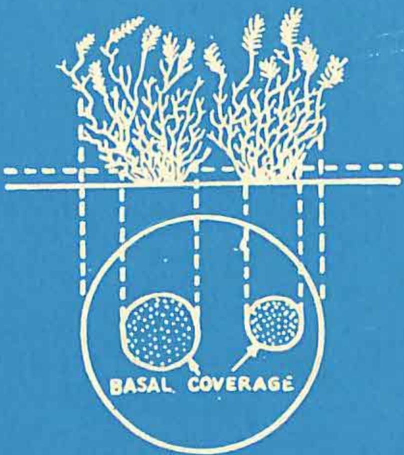
PLANT ECOLOGY
AND
SOIL SCIENCE



SHUKLA & CHANDEL

PLANT ECOLOGY
AND
SOIL SCIENCE

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PREFACE TO SIXTH EDITION

In this edition, the general plan of previous edition for presentation of subject-matter has been retained, but within the framework, the book has been completely revised, enlarged and brought up-to-date keeping in view the requirements of students of different Indian universities.

In this enlarged edition three new chapters have been added. In the chapter 11, an account of 'Plant Ecotypes' has been given and in chapter 12, a detailed description of 'Plant Indicators' has been incorporated. A complete chapter on 'Conservation of Natural Resources' has been prepared to cover all the aspects of natural resources which has been placed on chapter 14 at the end of Plant Ecology.

We are greatly obliged to many of our friends in India and abroad especially to Dr. M. U. Beg, Scientist, Indian Toxicological Research Centre, Lucknow ; Dr. M. P. S. Chauhan, Head of Botany Department, Y. D. College, Lakhimpur ; Prof. D. N. Rao of BHU ; Prof. G. S. Paliwal of Garhwal University and Dr. V. Shanker, Reader and Head of Botany Department, Gurukul Kangri University, Haridwar.

We express our thanks to Sri S.L. Gupta, Managing Director, S. Chand & Co. Ltd., New Delhi for his keen interest in bringing out the book in time.

In the last we are specially glad to record our sincere thanks to Sri Navin Joshi, Manager of Lucknow Branch, Sri Narendra Singh, Sri Bhatt of Lucknow Branch, Sri B.S. Sharma, Sri Surendra Singh of Head Office and Sri Bhagirath Kaushik, Manager, Nagpur Branch are also greatly acknowledged for their cooperation.

R. S. SHUKLA
P. S. CHANDEL

PREFACE TO THE SECOND REVISED EDITION

This book presents in concise form an interesting and uptodate account of the important concepts and principles of modern *Plant Ecology* and *Science*. The book will be found suitable for the biology students preparing for B. Sc. Degree examinations of Indian Universities. For the post graduate students it provides indispensable fundamental knowledge without which the most recent advances over the wide front can not be understood. While writing the book an effort has been made to attract all the categories of students by presenting the subject in straightforward and lucid style and by explaining and analysing the basic terms and conepts in a systematic way. We have tried to give extensive and detailed factual informations to those items that contribute toward an understanding of important concepts and principles.

The language of this book is very fluent and easy. The plants quoted in the text as examples are mostly common Indian plants and at certain places common Hindi names of plants are also mentioned so that the readers may not feel difficulty in understanding the subject. In a book of this type there can be no claim to originality of approach except in the manner of treatment and much of the information and views have been obtained from the prominent books, Magazines and Research Journals.

Though every care has been taken in printing, there may have crept some errors in the book. We would be glad to hear from teachers and students of the errors which may have escaped our notice ; any competent suggestions and healthy criticisms whereby the book can be improved will be most welcomed and thankfully acknowledged.

R.S. Shukla
P.S. Chandel

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I

ECOLOGY

The things of the world are classified into two major groups namely the living or biotic component and the non-living or abiotic component. The biotic component includes all types of living organisms, both plants and animals and the abiotic component includes the non-living materials (soil, water, air etc.) and the forces of nature (light, gravity and molecular energy). The living organisms exist in an environmental setting of which they are a part. Every aspect of life is influenced by the environment and the activities of organisms affect their environment. An aspect of biology which deals with the inter-relationship between biotic and abiotic components as well as the relationships among the individuals of the biotic component is called ecology. Organisms form interacting systems or communities, these communities are coupled to their environments by transfer of matter and energy and the communities and environment are interrelated. A functional system formed by communities and their environment is called *ecosystem*. Thus ecology is a science of ecosystems or totality of reciprocal interactions between living organisms and their physical surroundings. (Clark, M.E. 1973).

The word 'ecology', first proposed by a zoologist named **Reiter** in 1885, is derived from Greek words, *oikos* meaning the dwelling place or home and *logos* meaning the discourse or study; thus, the word ecology literally means the study of living organisms, both plants and animals, in their natural habitats or homes. It can also be defined as the study of life in relation to environment; the *environment* being the aggregate of all external conditions and influences which affect the life and development of organisms at a given spot. The most widely accepted definition of ecology was proposed by zoologist named **Haeckel**. According to him, '*Ecology is the study of the reciprocal relationship between living organisms and their environments*'. Recently, **Odum** has defined ecology as *the study of the structure and the function of nature*. This branch of science seeks to determine the effects of environmental factors on the growth, distribution and migration of the organisms and also deals with some other aspects of relationship between organisms and these factors.

Ecology, like biology, has been subdivided into plant ecology and animal ecology. Plant ecology deals with the relationship between plants and their environments and animal ecology is concerned with the study of relationship between animals and their environments. Ethology is the name now generally used by biologists to denote the scientific study of animal behaviour with special reference to the behaviour of animal in its normal environment. In recent years there has grown an idea that in biological organisation the plants and animals are closely interdependent and they react with one another in many ways and at a particular place plants and animals share the same set of conditions and same environment. Therefore, these two sub-divisions, plant ecology and animal ecology should be unified. In view of this reasonable fact, the authors of modern ecology have accounted for the study of both plants and animals in the environment.

Ecology and its Divisions

Ecology may be divided into **autecology** and **synecology**.

Autecology. Autecology is concerned with the study of individual animal or plant species or its population throughout its life history in relation to the habitat in which it grows, or in other words, it is a study of inter-relationship between individual species or its population and its environment.

Synecology. The other area of ecology which deals with systems of many species—whole communities or major fractions of communities and ecosystems is termed *Synecology* in English speaking countries, *biocenology* or biosociology by many Europeans. (Whittaker, R. H. 1970).

It is concerned with the structure, nature, development, and causes of distribution of communities. To understand the ecology of plant communities, the ecological life cycles (autecology) of at least most important plant species of the communities must first be studied. Thus, autecology forms a basis for the study of synecology.

The study of plant community structure is called phytosociology or plant sociology. The study of plant ecology merges with plant geography or phytogeography. This is a science which deals with the distribution of plants on or near the surface of earth and water and it also deals with the migration of species. Actually speaking there is no sharp line of distinction between plant ecology and plant geography. **W. B. Turrill** comments *that plant ecology is intensive while plant geography is extensive in outlook, but both are concerned with plants and in attempting to correlate observed structure and behaviour of plants with causes, both refer to the same sum total of environmental factor though the emphasis varies.*

Different Fields of Ecology

Different branches which are made to account for the various specific and detailed aspect of ecology are as follows:

1. **Habitat Ecology**. It deals with habitat as a central theme and plants and animals as only inhabitants. It includes forest ecology, grassland ecology, fresh water ecology, marine ecology, desert ecology, etc.

2. **Paleoecology**. It is concerned with the organisms and geological environments of the past.

3. **Cytoecology.** It deals with the cytological details of the species of populations in relation to different environmental conditions.

4. **Ecosystem ecology.** It deals with the structure and working of ecological systems in relation to space and time and also with the analysis of components of ecosystem. In this, special emphasis is laid on the reciprocal relationship between living and non-living systems.

5. **Conservation ecology or Resource ecology.** It is concerned with the proper management of plant, animal, soil, water and mineral resources for human welfare.

6. **Ecological energetics and Production ecology.** These modern branches of ecology are still in developing stage. These deal with the mechanisms and quantity of energy conversion and flow of energy through organisms. Energy production processes, rate of increase in organic weights of organisms in relation to space and time are also discussed in this branch of ecology.

Plant Ecology and other branches of Science

Ecology is a synthetic branch of biological science which draws source materials from many other sciences. It is fundamentally related to morphology, taxonomy, physiology, biochemistry, cytology, genetics etc. Various other sciences, such as, physics, mathematics, statistics are also being increasingly used in the study of ecological problems. Application of radioactive isotopes, use of many modern and advanced instruments like spectrometer, infrared gas analyser, flame photometer, computors in the analysis of data, calorimeters, phytotrons for culturing the plants in environment controlled chambers and many other equipments are widely used in ecological researches. Besides botany, zoology, chemistry and physics, the knowledge of climatology, geography, pedology, and geology is also essential in the study of complicated problems of plant ecology.

Application of plant ecology

The study of plants in their environment has yielded a large body of knowledge which provides aids to the science of conservation of natural resources. The knowledge of ecology is of great help in controlling soil erosion, reforestation, restoration of wild animals as well as grassland vegetation, and flood control. Plant ecology is directly related to silvics and silviculture and other branches of forest biology. In *British Commonwealth Forestry Terminology* (1953), **Silvics** has been defined as the study of general characteristics and life history of forest trees and crops with particular reference to environmental factors, as the basis for practice of silviculture while the **Silviculture** has been defined as the art and science of culturing forest trees and crops.

Every farmer or gardener is ecologist, since by such practices as cultivation, irrigation, artificial pollination and spraying, he affects the plant behaviour.

Knowledge of ecology is being applied in agriculture, food production and horticulture. The soil conservation practices are in use these days in agronomy. The modern ecology revolves round the biological production processes and ecological energetics. The International Biological Programme (IBP) was launched since July 1, 1967 to study the biological basis of organic productivity and conservation of natural resources in relation to human welfare. Launching of this programme has given impetus to the ecologists all over the world and over 70 nations including India have participated in the IBP studies at either national or international level. The future of ecology and indeed of Biology is likely to be changed by some international programmes such as 'Man and biosphere' (MAB).

The history of ecology in India is not very different from that of any other country in the world. Indeed, it has been much influenced by western school which provided the leadership. Publications of botanical explorations by Dudgeon (1920), Saxton (1922), Bor (1942), Osmaston (1926) and Champion (1936) provided enough opportunity for ecological investigation in India. Professor F. R. Bharucha, a student of Braun-Blanquet, established the first school of ecology at Bombay. This school contributed a great deal of informations on the biological spectra of different regions of India and on the phytosociology of grass and forest vegetation. The second school of ecology developed under the leadership of Professor R. Mishra first in Sagar and later at Varanasi. At present, many secondary schools of ecology are emerging at Ujjain, Ahmedabad, Pilani, Jodhpur, Pondicherry etc., and ecologists in these centres are engaged in different fields of study.

Questions

1. What is ecology ? How it is related with other branches of biology ?
2. What are different branches of ecology ? Why study of ecology is important for man ?

2

THE ENVIRONMENT

In ecology, the reciprocal relationship between an organism or a group of organisms and its environment is studied. The environment literally means the surrounding. The environment is the aggregate of all those things and set of conditions which directly or indirectly influence not only the life of organisms but also the communities at a particular place. It is comprised of a number of factors, which interact with one another and also influence the responses of the organisms. Any external force, substance or condition affecting the organisms in any way is referred to as environmental factor. Soil, moisture, wind and temperature are, thus, factors and the environment, thus, is sum total of all such factors. The natural place where organisms of communities of organisms live is called *habitat*. The habitat implies a particular set of environmental factors and is, therefore, generally used in a more concrete sense than the environment.

All the living organisms on earth are confined to the thin outer shell of atmosphere, ocean and earth crust. The life supporting environment of planet earth is called biosphere. The biosphere is composed of three chief media—air, soil and water and on this basis biosphere has been divided into three sub-divisions : *Atmosphere*, *lithosphere* and *hydrosphere* respectively.

The environmental or the habitat factors influence the characters and composition of individual plants and plant communities. Any feature of an organism or its part which enables the organism to exist under conditions of its habitat is called an *adaptation*. An organism accumulates many adaptive features in it. Such features may ensure a degree of success either by allowing the plant to make full use of the amounts of nutrient, water, heat and light available to it or by providing a significant amount of protection against some unfavourable or adverse factors, such as very high or very low temperature, drought, parasitism and so on. The adaptive features of organism may be a hereditary (*i.e.*, they may be genetically controlled) or they may be induced by the habitat factors.

In an ecosystem the species and its environment are taken as a complex "*Whole*." Environment, as pointed out earlier, in itself is a complex of factors acting, reacting and interacting with the organism complex.

Ecological factors are many and diverse and often intricately mixed and interdependent. These factors, either singly or in combination influence and determine the presence or absence, vigour or weakness, and relative success or failure of various plant communities in a particular habitat.

Main environmental or ecological factors

The environmental conditions which influence the life and development of plants are grouped into four main classes which are as follows :

(1) Climatic factors (related to aerial environment) ;
(2) Edaphic factors (related to soil conditions) ;
(3) Physiographic (topographic) factors ; and
(4) Biotic factors.

As already mentioned, these ecological factors are inter-related and intricately mixed. They work through one another acting and reacting together, as for example, the change in physiographic conditions at a place may bring about a change in local climate that, in turn, may affect the soil and competition impress.

CLIMATIC FACTORS

Climate is one of the important natural factors controlling the plant life. Its study is called climatology. The climate includes the following main factors :

(1) Light
(2) Temperature
(3) Precipitation and atmospheric humidity
(4) Wind

LIGHT

The radiant energy coming from the sun in the form of visible spectrum is called light or luminous energy. Radiation that penetrates the earth atmosphere consists of electromagnetic waves of a wide range in wavelengths. A beam of light is pictured as a shower of particles called *photons*. Each photon carries a certain amount of energy called *quantum*. The energy varies inversely to the wave length of the spectrum. The solar spectum in the earth's atmosphere has been analysed on the basis of wave-lengths of different radiations (Fig. 2.1). The solar radiations which penetrate earth's atmosphere consist of a band of visible (to man) light and a small proportion of ultraviolet and infrared radiations. It is not known whether the long radio waves have some ecological importance to plants. The visible light lies in the range of 400—750 mμ. When the visible sun light is passed through a prism it is dispersed into a series of wavelengths exhibiting seven different colours—*violet*, *indigo*, *blue*, *green* *yellow*, *orange*, and *red* (VIBGYOR). The wavelength of Ultraviolet (2% of the radiation reaching the earth surface) is below 390 mμ and that of infra-red above 750 mμ (1 millimicron or mμ=1/1000 of a micron. Since a micron is 1/1000 of a millimetre, a milliμ (mμ) is equal to ·000001 mm or 10^{-7} cm). In working with ultraviolet and other rays of shorter wavelengths Angstrom unit is used ($10\text{Å}^{0}=1m\mu$). The photochemical activity is greatest at the violet end. Ultraviolet (UV) thus, has the greatest killing effect on the protoplasm. It helps in the synthesis of anthocyanin in leaves and inactivates the growth hormones and thus checks stem growth. Microbes injured by ultraviolet rays are often rejuvenated by exposure to visible light. X-rays and γ-rays show high degree of ionising effects. They cause mutation in the living systems and in high doses they are absolutely fatal. Infra-red radiations are not so powerful as may stimulate biochemical reactions. These radiations have high heating effects. They exert influence on stem growth and germination. The radiations of wavelengths shorter than 290 $m\mu$ never reach to the earth surface.

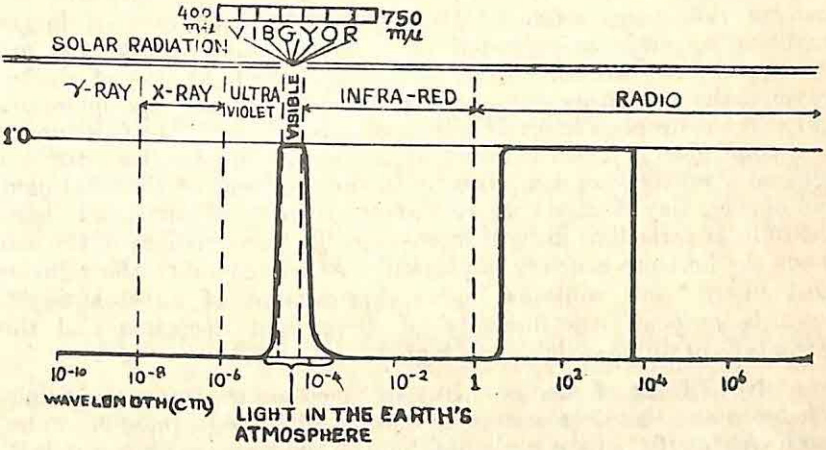

Fig. 2.1. Solar Spectrum.

Light is usually measured by an electric instrument called light-meter or photometer which consists of a light sensitive photoelectric cell. The intensity of light is directly recorded on a dial of the photometer. It is measured in foot candle or lux. Photometers are never exposed to direct sunlight. Actually, light reflected by a thick white paper placed on the ground or surface of the plant is measured. For ecological purposes light intensity is measured in a number of habitats for different species. This will enable one to know whether the species are shade loving or light demanders.

Spatial Variations in light intensity

Light intensity differs from place to place. The spatial variation in light intensity may be caused by the following :

(a) **Effecting atmosphere**. When the light passes through the atmosphere of the earth, a small proportion of light of shorter wavelengths becomes absorbed by atmospheric gases, mainly nitrogen and oxygen. The places at high altitudes receive brighter light than those at lower altitudes (above the sea level) because at higher elevations the atmosphere is thinner than that at low elevation.

Atmospheric vapour exerts a powerful screening effect and for this reason the intensity of light is much greater in dry areas than in wet regions. In a cloudy day, the light may be reduced to 4% of the normal intensity. When the atmosphere is saturated with fogs and clouds, a relatively high proportion of light rays of longer wavelength, such as infra-red and other visible radiations, are absorbed by the atmospheric moisture and the light rays of shorter wavelengths and ultraviolet rays are absorbed by the gas molecules and vapour droplets and the light reaching the earth surface under such conditions is called diffused light or sky light. The diffused light on over-cast day comprises up to cent per cent of the total light and on clear day it may comprise about 10-15% of the total light. Latitudinal variations in light intensities due to the height of the sun above the horizons are very important. At the equator, the light is most intense and contains highest proportion of direct sunlight. Towards the poles, the intensity of direct light decreases and the percentage of diffused light goes high.

(**b**) **Effect of water**. In water medium the intensity of light is reduced and this decreases progressively with the increase of water depth. About 10% of the sunlight falling on the water surface is reflected and 90% of that penetrates water and is modified in respect to intensity, spectral composition, angular distribution (refraction) and time distribution. Phytoplankton, zooplankton and suspended particles either reflect or absorb the light rays. Submerged plants get weaker lights than the plants on the surface of water get. It is so because a proportion of light falling on the water surface is reflected and the major portion of the penetrating light is absorbed by upper layers of water. When light reaches on the surface of water the major proportion of rays of shorter wavelengths. *i. e.*, violet, indigo, blue and green, are reflected and other lights are partly absorbed. This is why bodies of water appear bluish green in colour. Reflection of light is increased several times in the rough water surface. There is a selective absorption of light at various depths in water. The rays of longer wavelengths are absorbed near the surface and in general light rays of shorter wavelength penetrate deepest. Thus, infra-red rays are absorbed in upper layers of water (about 4 metres); red and orange rays are completely absorbed upto the depth of 20 metres; yellow rays may penetrate up to 50 m. and green and blue rays penetrate upto 80 to 100 m. deep. Violet and ultraviolet rays penetrate beyond 100 m. depth and no light penetrates beyond 200 m. depth.

Depending upon the penetration of light, oceans are divided into the following three zones :

(a) Euphotic zone (upto 50 m. depth)

(b) Disphotic zone (80 to 200 m. depth)

(c) Aphotic zone (below 200 metres of depth)

In the oceans, algae are distributed according to wavelengths of light rays that their colours are best suited to absorb and utilize : green algae are found in intertidal zone, brown algae descend somewhat deeper and red algae are characteristc of deep oceanic water.

Light has got sufficient power of penetration. Photosynthesis may take place in some plants which are covered under as much as 40 cm. thick snow.

(c) **Effect of suspended particles**. Dust, smoke and other solid particles dispersed in the air or water have great screening effect. In smoky industrial cities, the smoke may reduce 90% of light.

(d) **Effect of the layers of vegetation**. In complex plant community, for example, forest, the tallest plants receive full sun light, undershrubs receive subdued sunflecks or diffused light, herbs and epigeous cryptogams grow in still weaker light. In dense forest the leaves completely check the penetration of light and less than 1% of total sun light reaches to the surface.

Temporal variations in light

The light intensity during summer is much higher than that in winter. It is weak at sunset in winter and comparatively stronger during the mid-day hours. This periodical fluctuation in the intensities of light is due to the change in the angles of radiations reaching the earth. When the sun is at the horizon the solar rays travel through approximately 20 times the thickness of the air they have to penetrate when the sun is overhead in the noon. At the equator, the day light prevails 12 hours out of every 24 hours in both the seasons, summer and winter. In the polar regions, the day length (photoperiod) becomes longer than 12 hours in summer and shorter than 12 hours in winter. The skylight or diffused light available before sunrise and after sunset is of great ecological importance. Moon lights play some important role in the plant life. It sometimes satisfies light requirements of certain seeds, promotes starch hydrolysis in the leaves, affects nocturnal leaf movement in legumes, and stimulates the sexuality in certain marine algae.

Importance of light to plants

Light affects many physiological activities of the plants. Light affects the following aspects of plant life :

(1) **Photosynthesis**. Out of the total solar energy reaching to the earth, only about 2% is used in photosynthesis and about 10% is used in other physiological activities. It has been estimated that a corn plant utilises only 0·13 per cent of light energy. All wavelengths of light are not utilised by a plant. Green light is completely reflected by green parts of the plants making them look green. Red and blue green are the two maxima of absorption of light. The green plants, the producers of ecosystem, synthesize their food (carbohydrates) from water and CO_2 in presence of sun light. The solar radiations provide energy for this process. In this processs radiant energy of the sun available to the plants is converted into the chemical energy by chlorophylls. The chemical energy stored in food is utilised in various other biochemical activities in the plants. The rate of photosynthesis is greater in intermittent light than in the continuous light. The relationship of light intensity with photosynthesis in terrestrial as well as in aquatic plants follows the general pattern of a

linear increase upto an optimum or saturation intensity followed by a decrease at high intensities (Rabinowitch, 1951; Thomas, 1955).

Light plays important role in the development of plastids and pigments. It has marked effect on the number and position of chloroplasts. The upper part of leaf which receives full sunshine has large number of chloroplasts which are arranged in line with the direction of light. At high intensity, the photo-oxidation of enzymes reduces not only the rate of carbohydrate synthesis but also that of protein synthesis. The protein synthesis is especially reduced by high intensity of light. High intensity of light, however, influences the formation of anthocyanin pigment. It is for this reason, alpine plants have beautifully coloured flowers.

(2) **Respiration**. There is no direct effect of light on the respiratory activity in the plant body. Indirect effect is much important because in presence of light the respiratory substrates are synthesized. Under certain conditions, such as, in shade and under water, the light becomes a limiting factor and the photosynthesis is not sufficient for effective growth. Under such conditions, the rate of photosynthesis is just sufficient to meet the need of respiration. This is called *compensation point*. At this point, the dry weight of plant does not increase. The compensation point differs in different species and in different individuals of the same species at different ages. In many plants the respiratory rate increases with the increase in the light intensity. Ranjan and Saxena have studied the effect of light intensities on respiration rate in many plants and have shown that respiratory rate could increase in *Canna*, *Nerium*, *Bougainvillea* with the increase in light intensity. However, in some other plants respiration rates decreased slightly in intense light. The rise and fall of respiration rate may be due to the effect of light on the permeability of plasma membrane, change in the viscosity of the protoplasm and photo-oxidation of enzymes. The permeability and viscosity increase with the increase in light intensity up to certain optimum. Light, however, has got very little effect in respiratory process of lower plants and thallophytes.

(3) **Opening and closing of stomata and in transpiration**. Mostly the stomata remain opened in the light and closed in the dark. Light brings about phosphorylation and conversion of starch into soluble sugars in the guard cells and thereby increases their osmotic pressure which, in turn, causes inflow of water in the guard cells. The increase in the turgidity of guard cells causes widening of gap between two guard cells. The opening of stomata increases the gaseous exchange and also increases the rate of transpiration during day period. Increase in the light intensity above the optimum shows detrimental effects because the increased transpiration in the intense light is injurious to plants.

(4) **Growth and flowering of plants**. Light shows many fold effects on the growth of the plants. Growth of plants depends especially on the intensity, quality, duration and direction of light. High intensity of light inhibits the production of auxins or growth hormones and consequently it influences the shapes and sizes

of plants. Plants growing in darkness or insufficient light produce maximum amount of growth hormones as a result of which they are elongated with slender pale yellow stem and small leaves. The plant growth is slow in the light of high intensity. Red light favours the growth. Lights of shorter wavelength, except violet, are detrimental to plant growth.

Duration of light is also very important. Actual duration or length of the day (photoperiod) has been shown to be important factor in the growth and flowering of wide variety of plants. The controlling effect of the photoperiod, known as photoperiodicity, is currently an active field of physiological ecology. According to their response to length of photoperiods, the plants have been classified into three well defined groups :

(i) **Long day plants**. Plants which bloom when the light duration is more than 12 hours per day, as for example, radish, potato, spinach, etc.

(ii) **Short day plants**. Plants which bloom when the light duration is less than 12 hours per day, as for example, cereals, tobacco, cosmos, dahelia, etc.

(iii) **Day neutral plants**. Plants which show little response to length of day light, as for example, tomato plant.

Recently it has been shown that photo-periodic stimulus for flowering is also controlled by thermal points. Azzi (1957) has shown for the first time that initiation of flowering in a plant occurs at certain constant which is specific for a particular species. This constant is called Azzi's constant which is expressed as follows :

Azzi's constant = Total duration of light in hours
+ total mean temperature in °C.

Chinoy (1960) has confirmed this constant and called it **Photo-thermal quantum** requirement of a species. Thus, an increase in temperature will decrease the duration of light required for flowering. This information can be applied to advantage in autecological studies of certain crop plants.

Plants which receive direct sun light are called *heliophytes* and those growing in the shades are called *sciophytes*.

Heliophytes exhibit the following features :

(*i*) Stem with short internodes and long lateral organs ;
(*ii*) Roots numerous and profusely branched ;
(*iii*) Thick cuticle ;
(*iv*) Well developed palisade and weakly developed spongy tissue in the leaf ;
(*v*) Well developed xylem with thick rays ;
(*vi*) Small intercellular spaces in the tissues ;
(*vii*) High respiration rate and much rapid transpiration ;
(*viii*) Vigorous flowering and fruiting ;
(*ix*) Early appearance of flowers ;

(*x*) Low chlorophyll content ; and

(*xi*) Proper development of mechanical tissues.

In the absence of light, the growth is very poor and plants show etiolation. The stem becomes tender, narrow, and long and the leaves become pale green, soft and small. Thus, light is essential for the normal and healthy growth of plants.

(5) **Movement**. Light affects the movement in some plants. The stems, roots and leaves show different responses to light. The effect of sun light on the plant movement is called heliotropic effect. The stems elongate toward the source of light (positively phototropic) and the roots are negatively phototropic. The leaves grow transversely to the path of light. In order to receive maximum sun light, the leaves are oriented on the stem in such a way that they do not overlap each other.

(6) **Germination of Seeds**. The seeds when moist are very sensitive to light. In some cases, the germination of seeds is retarded in light. The quantity of light needed for the stimulation of embryo varies in different seeds.

Light is an important factor in the distribution of plants. Some plants grow in full sun light, while others prefer to grow in shade. Bormann (1956) describes an interesting situation in certain species of pine in which young seedlings are shade adapted while older seedling and young trees do not grow well in shades.

TEMPERATURE

The most influential factors in the climate are temperature and moisture. The temperature affects the vegetation either directly or indirectly. Directly it appears in two ways :

(*i*) It affects the physiological processes of plants and consequently their growth and size ; and

(*ii*) It determines which species can survive in a particular region. The different species of plants show a wide variation as regards their tolerance to temperature range and fluctuation.

On our planet, organisms can carry on their life activities over a relatively narrow temperature range extending from 0°C to 50°C and every plant has a specific range of temperature requirement. This range differs from species to species. Plants do not thrive in places with higher or lower temperatures than their ranges.

Generally, at 40°C the protoplasm undergoes such changes as minimal to plant life and it dies at temperatures above 90°C. However, some plants carry on their life processes at high temperatures but at 70°C temperature plants rarely survive. At temperatures below freezing point plants generally die because of rapid crystallisation of protoplasmic water which results in mechanical injury. Air dried yeast can endure temperature as high as 114°C. Bacteria can endure temperature between 120°C and 130°C. A few fungi can withstand temperature upto 89°C. Air temperature above 32°C is most favourable for tropical plants. Existence of vegetation has been recorded between 26°C (some conifers) to 66°C (Desert plants). The temperature range can be said minimum, optimum (most suitable temperature for life and growth) and maximum (beyond which no survival is possible).

The general inability of protoplasm to endure high temperature can be ascribed in large part to the sensitivity of its enzymes to heat. Catalytic proteins in nearly all cases are irreversibly inactivated by exposure to high temperatures (usually greater than 50°C) for any length of time. They are, however, able to withstand lower temperatures even below the freezing point of water. The ability of the cell to endure sub-freezing temperatures seems to depend principally upon the avoidance of ice formation. The appearance of ice crystals in cells is almost always associated with the death of these cells, due in part to mechanical damage inflicted on the subcellular structure by the ice crystals themselves. Death may be also due to removal of water from the protoplasm by ice formation in the intercellular spaces, thus dehydrating the protoplasm.

According to the heat requirement of plants, Raunkiaer divided the gross vegetation into the following types :

(a) **Megatherms**. Plants of warm habitat which require high degree of heat throughout the year. They are found in areas with tropical climates e.g. plants of deserts.

(b) **Mesotherms**. Plants of habitat which is neither very hot nor very cold. These plants cannot stand extremely high or low temperatures and they are found in tropical and subtropical habitats.

(c) **Microtherms**. These are the plants of cold or temperate habitat and require low temperatures for their growth. Such plants cannot tolerate high temperature. They may also be found in tropical and subtropical areas at high elevations where temperature conditions are less extreme.

(d) **Hekistotherms**. These are the plants of cold and alpine regions. They do not thrive well in heat and can stand long very severe winter.

Many plants are very sensitive to temperature. The sudden fall in temperature is injurious because plant tissues are badly affected with it. Forests suffer from night frost on the east side where the sun rays strike very early in the days. As an adaptation against frost, the starch of plants changes to fats or oils in the autumn. The fatty oils depress the freezing point and thus increase the power of resistance in plants against frost. The leaves of plants in the coldest lands store fats. Pentosans, mucilage and pectic substances which have high water retaining power are abundant in many plants. They decrease the danger of plants from desiccation and consequent death. Dried seeds and spores are not affected with freezing because there remains no liquid in them that can freeze. Due to removal of water from seeds, the cold resistance of seeds of certain plants increases up to the extent that their exposure for 3 weeks to —190°C, does not diminish their germinability.

The temperature stimulates the growth of seedlings. The optimum temperature for seed germination ranges between 20°C and 27°C.

The absorption rate is retarded at low temperature. Photosynthesis operates over a wide range of temperature. Most of the algae require lower temperature range for photosynthesis than the higher plants. The photosynthesis continues even at 80°C in some desert plants.

The rate of respiration increases with the rise of temperature upto a certain level, but beyond the optimum limit the respiration rate shows marked decrease. The rate of respiration becomes doubled at the increase of 10°C above the optimum temperature provided other factors are favourable (*Vant Hoff's law*). High temperature generally favours the growth of plants, but for some crop plants low temperature is beneficial. If the temperature ranges of winter varieties are lowered up to 0°C to 5°C, the seeds sown in the spring season will grow luxuriantly and the plants will mature and flower at normal time. The process by which temperature range of plant is lowered in order to get early crop is called *vernalization*. This practice is very common in cold countries.

Temperature determines the growth of many plants. Cotton prefers high temperature. Potato gives highest yield in low summer temperature. Growth of plants is retarded at high temperatures.

Temperature in combination with humidity and other factors helps in the spread of diseases in plants. Low temperature and high humidity favour the rust attack. Low temperature, high humidity and cloudy weather favours the damping off, seedling blight, foot rot and root rot diseases of cucurbits, tobacco, papaya and ginger.

Temperature varies from place to place and likewise the vegetations of different areas also differ considerably. Desert plants grow in extreme heat, aquatic plants grow in low temperature range, and grasses prefer to grow in the area of moderate temperature.

Temperature in combination with moisture determines the general distribution of vegetation. Northern, southern, tropical and temperate vegetations depend solely upon temperature and moisture.

PRECIPITATION AND ATMOSPHERIC HUMIDITY

Water is one of the most important climatic factors. It affects the vital processes of all the living beings. It is the plenary agent that sets in motion the nutrients of the soil and makes them available to plants. It affects the morphology and physiology of the plants. It, in combination with other factors, regulates the structure and distribution of plant communities.

In nature, water may be found in vapour, liquid and snow or ice states. In the atmosphere, water is found in the form of vapour. The quantity of water retained in the atmosphere depends on temperature and wind. Vapour increases in the atmosphere if the temperature rises and pressure decreases. At certain temperature and pressure, the maximum water-laden air is called saturated atmosphere. At saturation point, if the temperature is lowered the water holding capacity of atmosphere is reduced which causes the condensatien of water vapour in the form of rain drop, dew, frost, sleet, snow, etc. This is *precipitation.*

The water vapour present in unit volume of air is called *absolute humidity.* This is expressed in terms of percentages of water vapour present in unit volume air at certain temperature. The amount of water required to saturate the same unit volume of air under constant physical conditions is called *relative humidity.*

Water of atmosphere reaches to the earth's surface through precipitation and from earth's surface it reaches to the atmosphere through evaporation and transpiration (Fig. 2·2). Thus a continuous circulation of water from earth to atmosphere and *vice versa* is maintained in nature. This is called *water cycle* or *hydrologic cycle.* It has been estimated that about 80,000 cubic miles of water from the oceans and 1,500 cubic miles of water from lakes and land surface evaporates annually. The total evaporation is equalled by total precipitation (of which about 24,000 cubic miles of water falls on land surface). The main source of water for terrestrial plants is rain water. Penck using precipitation-evaporation ratio, has classified the climate as follows :

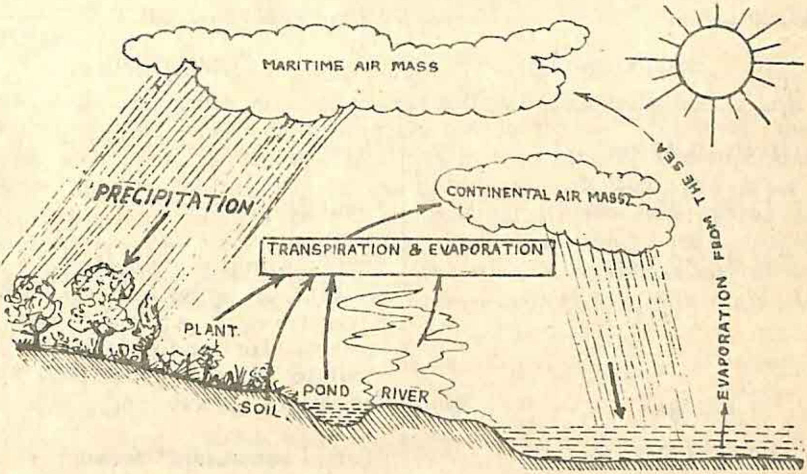

Fig. 2·2—Hydrologic cycle in nature.

(*i*) *Arid* —It is characterised by the condition that evaporation is greater than precipitation.

(*ii*) *Arid-humid*—When evaporation is more or less equal to precipitation.

(*iii*) *Humid* —When evaporation is lesser than precipitation.

The total rainfall, especially the distribution of rainfall throughut the year is one of the leading features of climate. Rainfall map of the world corresponds very closely with the distribution of great vegetational zones in the world.

Sudden and heavy rains are not so beneficial as are moderate and continuous rain because in the heavy rain a large amount of water is lost from the surface of soil as run off and the soil is eroded.

Rainfall is determined largely by geography and pattern of large air movements of weather systems. When the moisture laden winds blow from the oceans towards the high mountain they deposit most of the moisture on the ocean-facing mountain slopes with a resulting 'rain shadow', and produce desert on the other side. The higher the mountain the greater is the precipitation of moisture over it. This is the main reason why deserts are usually found behind high mountains. The deserts are also found along the sea coasts, where wind blows from large interior dryland areas rather than off the ocean.

The amount of rainfall in different localities largely determines the nature of vegetation therein. The following tabulation gives a rough idea about the plant communities that may be expected in regions with different amounts of annual rainfall.

Annual rainfall	Vegetation
1. 0 to 13.24 cm	Desert
2. 13.25—35.1 cm	Semiarid grass land
3. 35.2—63.5 cm	Dry subtropical grass land, savanna (a grass land with scattered trees or scatter clumps of trees—a community type intermediate between grass land and forest) open wood land
4. 63.6—114.3 cm	Humid subtropical forest
5. 114.4—203.2 cm	Tropical rain forest

Snow, which may lie on the ground to form a valuable protective blanket and also a reserve of water, is apt to limit the growing season by its late melting.

Hail, a special type of precipitation during the summer season in the form of small ice pieces, may cause serious injuries, especially to young crops.

Dew and sleets make a very vital contribution to precipitation in the regions of low rainfall. Dew and ground fog may be important to plants not only in coastal forest but also in deserts near the sea coasts where they provide much of surface water on which the ephemeral plants depend.

The atmospheric humidity influences directly the form and structure of the plants. It directly affects the transpiration rate of the plants. In dry atmosphere transpiration rate increases and as a result of this the water content of the leaf tissues decreases and the leaves wilt temporarily. Water requirements of different plant species differ considerably. Some species on one extreme, thrive well in the region with an annual precipitation of 10 cm while some, on the other extreme, grow only when they are submerged in water. On the basis of their water requirements, the plants are grouped into three ecological groups :

(*i*) *Hydrophytes.*	Plants adapted to aquatic environment.
(*ii*) *Xerophytes.*	Plants adapted to grow in dry lands where water content is low.
(*iii*) *Mesophytes.*	Plants living in the habitat that usually shows neither an excess nor a deficiency of water.

The actual effects of water on the plants may be complicated by other conditions, such as temperature and atmospheric humidity. The combination of temperature and precipitation plays vital role in determining the broad features of plant distribution on the earth surface.

The temperature exerts more limiting effect on the organisms when the moisture conditions are extreme (*i.e.*, either very high or very low) than when such conditions are moderate. Likewise moisture also plays a more critical role in the extremes of temperature. Some modern climatologists taking into consideration the quantitative measures, effectiveness and seasonal distribution of moisture and temperature have classified the climate into temperature, tropical, polar and high altitude climates. The characteristic features of these climates and peculiar type of vegetations restricted to them are given in the following chart.

Climate	Characteristic features of climate	Vegetation
1. Temperate climate	Cold and moist with well marked seasonal and diurnal fluctuation, average annual rainfall more than 762 mm (30″), warmest month above 10°C	Luxuriant vegetation in favourable situation. Trees and shrubs dominant, and herbs exceeding trees and shrubs in number.
2. Tropical climate	Warm and widely humid with mean temperature of the coldest month usually 17.8°C and rainfall very heavy (200-400 cm per annum). Frost and snowfall are usually unknown. Little or no seasonal variation.	World's luxuriant rain forests in the regions of high rainfall. Scrubs, grass land, desert community in the regions of decreasing rainfall.

Climate	Characteristic features of climate	Vegetation
3. Monsoon area.	It is characterised by dry and wet seasons. Rainfall very heavy	Deciduous trees and shrubs.
4. Climates of polar regions and high altitudes.	Warmest month below 10°C. Precipitation mostly in the form of snow and widely distributed. Annual rainfall less than 254 mm (10″). Owing to low temperature, the relative humidity is high and evaporation rate is low. In the regions of high altitudes there is continuous light in summer and darkness in winter.	Vegetation mostly low and scant. Dwarf shrubs and grasses dominant. Mosses and lichens are common.

WIND

Air moves from high pressure to low pressure, causing wind. The atmospheric air consists of a number of grass particles and other constituents. The proportion of grass in atmospheric air is kept constant to a fair degree :

Nitrogen	78%
Oxygen	21%
Carbon dioxide	0.03%
Argon and other gases	0.93%

The other constituents vary depending upon habitat condition. They include water vapour, smelter gases, dust and smoke particles, microorganisms carried on these particles, pollen grains and spores etc.

The effects of wind on the vegetation are important. The wind exerts an influence upon both configuration and distribution of plants. It commonly affects other ecological factors, as for example, the water content and temperature in a given area, through its effect on evaporation. It plays both positive and negative roles in the atmosphere, for instance, it has drying effect upon soil and may occasionally act in opposite direction bringing in moist air that reduces the transpiration and evaporation and may actually lead to the deposition and precipitation of moisture. The following are the important effects of wind on vegetation :

(*i*) Wind increases the water loss by constantly removing the air saturated with water vapour from the intercellular spaces of the leaves and bringing unsaturated air in contact with leaves and young shoots.

(*ii*) Mechanically, wind causes erosion of soil and abrasion of vegetation through removal of particles and physiologically, it decreases the growth of plants by way of reducing the moisture content of air and reducing the turgidity of plant parts on which it impinges. Moist air promotes the growth of mesophytes.

(*iii*) In strong dry and hot winds, young parts of plants may become shrivelled and killed in a few hours and the surface of soil may become dry.

(*iv*) In open situations, e.g.. sea shores and high mountain tops, where the strong winds blow all the year round in one direction, the trunks and branches are twisted chiefly in the direction, of prevailing wind. In such plants generally the growth of buds becomes checked on windward side (Fig. 2·3).

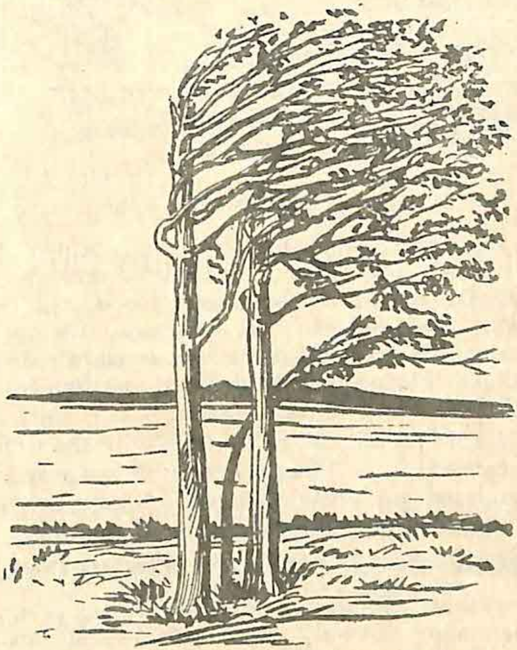

Fig. 2.3—Figure shows the effect of abrasive ice particles and strong wind on the branch growth. The buds on the windward side are either killed or they grow opposite windward side.

(*v*) In strong wind, big trees are uprooted and small plants and grasses are affected but to a very little extent. By strong wind weak plants like wheat, maize, sugarcane, jwar, etc. are bent against the ground. These prostrated plants, if their stems are not too mature, may again become partially erect. This is due to differential growth at the meristematic lower nodes of these plants.

(*vi*) Wind is an important agent for the dispersal of pollen grains, fruits, seeds and spores of the plants. In deserts, the strong wind carries the sand and seeds. Thus, it plays important role in local distribution of plant species or communities of plants. Some types are wind resistant but some may be totally dependent on wind for their dispersal. Many plants are unable to flourish or even exist in the exposed situations if they are brought to such places by wind. Strong wind causes injuries to plants growing at high altitudes. In desert, the storm results in big sand-dunes which cover the vegetation (Fig. 2.4).

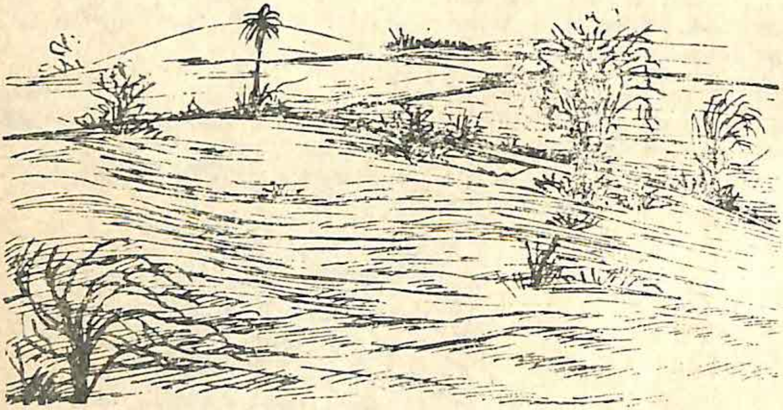

Fig. 2.4.—A view of sand dunes in the desert.

(*vii*) In the areas subjected to strong winds, the leaves of plants become small and rolled. The transverse section of stem shows eccentrically developed secondary wood, *i.e.*, the diameter of the trunks in the direction of wind becomes greater than that at right angle to it. The plants in such areas show extensive development of mechanical tissues which provide mechanical support and save the plants from wind injuries.

In India and many other countries of the world, unchecked winds have caused total disappearance of vegetation at certain places and rendered big areas deserted. Rajasthan desert in India is spreading eastward due to unchecked wind erosion.

MICROCLIMATE OR MICROENVIRONMENT

The important climatic factors, such as temperature, moisture, light and others show not only the regional variations but also show the local, horizontal, and vertical differences. The organisms occupying the same general habitat may actually be living under varied conditions. The term 'microclimate' or 'microenvironment refers strictly to combination of local atmospheric factors differing from the prevalent general climate (macroclimate) of the region. This is owing to the uneven topography, plant cover, etc. The microclimates are recognisable only in a very small area and they are sufficient to induce remarkable local variations in type and composition of flora. Thus, microclimate is of great ecological importance in studies of plant and animal behaviour.

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In one macroclimatic region there may exist a number of microclimates differing in several respects from the general climate, as for example, in a dense forest tall trees are exposed to high intensities of light and temperature, but shrubby plants growing in the shades of trees do not get the same climatic condition or in other words those shrubby plants grow in the atmosphere of dim light, high moisture and low temperature, and again at ground level the atmospheric conditions are changed so much that only some peculiar shade loving plants can thrive in it. Thus, it becomes very clear that climatic conditions of a particluar region vary at different levels, both vertically and horizontally.

Puri (1960) has summarised a good deal of informations on microclimates of plant communities. A number of physiological experiments can be conducted but nowadays emphasis is laid on work under controlled conditions. At some places phytotrons and climatotrons are used for such studies which constitute a series of chambers with devices to control different factors of climate. These experiments are useful in knowing the exact climatic requirements of a particular plant and defining the role of each factor. Although it is not easy to work out the effect of environment as a whole yet the results obtained by the study of individual factors if coordinated may provide important conclusions.

Importance of microclimate is realised in modern trends in agronomy and soil conservation. Interplay of variations in microclimate and soil conditions results in marked variations in agricultural potentiality within short distances.

EDAPHIC FACTORS OR SOIL FACTORS

Edaphic factors are those which are dependent on the soil as such—on soil constitution, soil water, soil air, soil organisms and so forth. Soils at different places vary considerably in their structure, components and properties. These differences in the soils are often largely responsible for differences in vegetation within the same climatic region, consequently they are of great significance in the distribution of plant communities.

Soil is defined as the unconsolidated top or superficial layer of earth's crust lying below any aerial vegetation and undecomposed dead organic remains, and extending down to the limits to which it affects the plants growing about its surface. Beneath the soil, lie the subsoil and unweathered rocks.

Soils commonly become stratified into layers or horizons, at different depths. The layers of soil at different depths show different compositions and natures. Normally three main horizons or groups of horizons can be recognised. These are the upper horizon or 'A' horizon, the middle horizon or 'B' zone and 'C' horizon (Fig. 2·5). These horizons are often divided by the use of appropriate subscripts, such as A_1. A_2, A_3. 'A' horizon or surface soil designates the top stratum which is subjected to marked leaching. It is a layer of greatest biological concern as the plant roots, small animals, and microflora and fauna are found here most densely. In this zone the

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concentration of the organic matter is highest, hence it is the dominant reservoir for plant nutrients.

The B horizon or the subsoil lying under A horizon has little organic matter, very few plant roots—and a sparse microflora and fauna. In it, iron and aluminium compounds are often accumulated. A and B horizons collectively represent the true soil. At the bottom of profile is the C horizon which contains the parent materials of the soil. In this layer the organic matters are present in small amounts and little or no life is noted. The essential components of most garden soils are as follows :

(*i*) Mineral particles (obtained by weathering or breakdown of the rocks) of variable size—40—50% by volume and 95% by weight;

(*ii*) Soil water—5·30%;

(*iii*) Soil air or soil atmosphere—25·30%;

(*iv*) Organic matter or soil humus arising from the death and decay of plants or the parts of plants and animals are added as manures —1 to 5% by weight;

(*v*) Soil organisms, including both soil flora and soil fauna, as for example, protozoa, nematodes, earthworms, bacteria. fungi, algae, etc. Fig 2.6A gives a rough idea about the percentage of various components of garden soil.

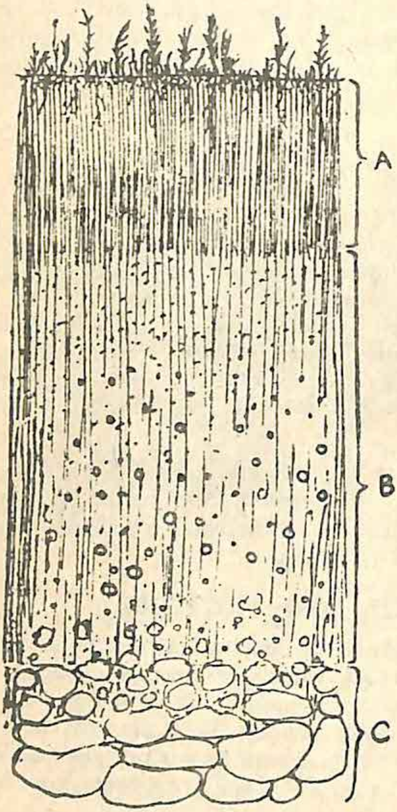


Fig. 2·5—Soil profile showing different horizons.

The important edaphic factors which affect the vegetation are as follows :

(*i*) Soil moisture ;
(*ii*) Soil reaction ;
(*iii*) Soil nutrients ;
(*iv*) Soil temperature ;
(*v*) Soil aeration or soil atmosphere ; and
(*vi*) Biotic components of the soil.

(i) **Soil moisture**. Plants absorb a small quantity of rain water and dew directly but a large quantity of water they take from the soil. Water held in the soil is found in the following forms (Fig. 2.6B).

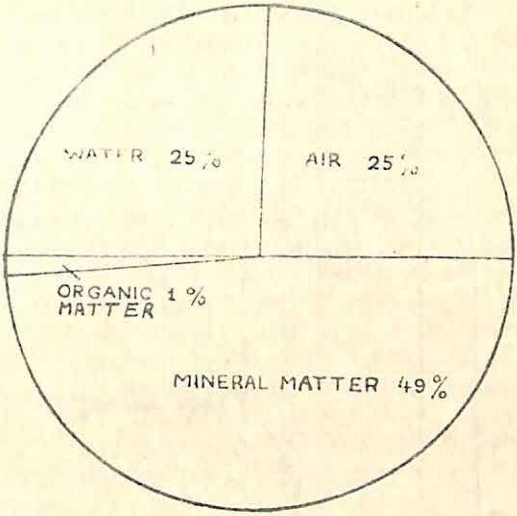


Fig. 2.6A—Soil components.

- (*i*) Gravitation
- (*ii*) Capillary water
- (*iii*) Hygroscopic water
- (*iv*) Water vapour
- (*v*) Combined water.

Gravitational water is free water which percolates downwardly through the pore spaces between soil particles and is accumulated in the pore spaces in the form of *ground water*. The amount of water present around the soil particles and held by surface tension and attraction force of water molecules is called *capillary water*. Capillary water remains readily available to the roots up to a certain soil moisture tension. Water which is absorbed on the soil particles and held on the surface of particles by forces of attraction and cohesion of its molecule is called *hygroscopic water*. This is the moisture remaining in air-dry soil. It can not be used by the plants. The soil atmosphere, like external atmosphere, also contains moisture in the form of *water vapour*. Water of chemical compounds is called *combined water*. Total water content of the soil is called *holard*. Water of the soil which is easily available to the plant is termed as *chresard* and water which is so strongly held by the particles as to be unavailable to the plants is termed as *echard*. The availability of soil moisture is influenced by many conditions, such as distance of water table from the soil surface, the rate at which water percolates downwards, the sizes of soil particles, the amount of annual rainfall and other precipitation, and the distribution of precipitation throughout the year. Water tends to promote the stratification of soil.

Soil water

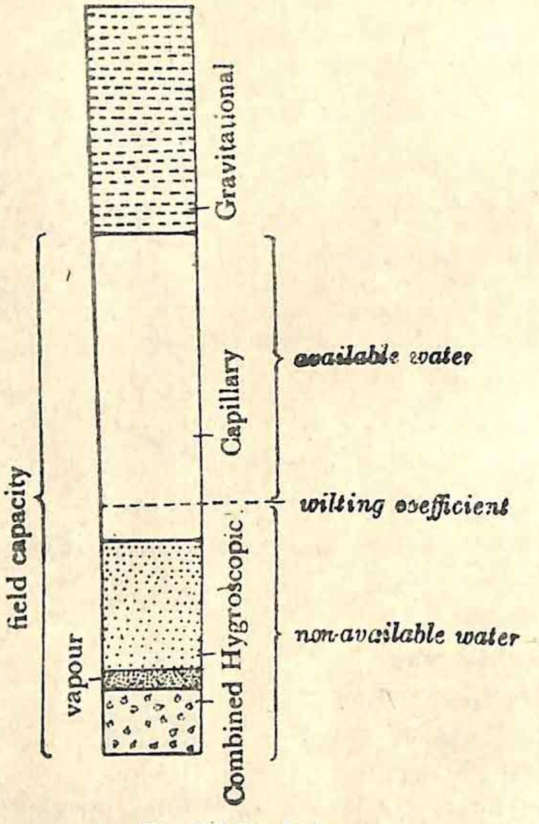


Fig. 2.6 B—Soil water.

Soil's available water is the chief factor responsible for local differences between plant communities. Heavily water logged soil is injurious for the growing plants because heavy accumulation of water in the soil reduces the soil aeration. Low water content in the soil is also injurious because it causes either temporary or permanent wilting of plants. Soil water is not only important in connection with direct fulfilment of water requirements of plants but it is also the medium by which mineral salts essential in the nutrition enter the plants in dissolved state.

(ii) Soil reaction. This edaphic factor influences the growth and distribution of the plants. The soil may show acidic, alkaline, or neutral reactions. The growth and productivity of many species of plants are critically, related to soil acidity. Species of *Rhododendron*, Cranberris are acid loving. Most of the field crops, such as barley, maize, soyabeans, tomato, rye, potato, flourish in slightly acidic soils. Many ferns and beech trees thrive best in slightly alkaline soils. Soil acidity is important in many ways; in the behaviour of soil solutes, and in the relation of roots to the soil. Soil acidity affects the availability of iron, manganese, phosphate, and other ions. In the acid soils, iron and manganese are available in appreciable quantities, but in the neutral or alkaline soils they are available in meagre quantities to green plants. The accumulation of calcium, sodium and magnesium salts in the soil results in alkalinity. The reaction of soil influences the absorption of water and soil solutes by roots through its direct effect on inhibition and permeability of root cell membranes.

(iii) **Soil nutrients**. The nature and availability of soil solutes are fundamentally important from the standpoint of plant nutrition. Normally, inorganic solutes are absorbed by the plants in the ionic forms. Different species of plants, no doubt they require the same ions for their normal development, require them in varying quantities. In saline soil where the percentage of salts in soil solution is high only halophytes (salt loving plants) grow. Some plants require lime and grow in calcium rich soils. Such plants are called *calcicoles* or *calciphytes*. Some plants do not thrive well when they grow in calcium rich soil. These species are called *calcifuges* or *oxylophytes*.

Humus, a dark amorphous substance formed by partial degradation of dead organic remains is an important source of mineral and organic nutrients of plants. The fertility of soil is usually correlated with its humus content. Humus is the main source of nutrients for soil micro-organisms and green plants.

(iv) **Soil temperature**. Soil temperature in combination with other edaphic factors influences the properties of soil itself and plants as well. Low temperature reduces the rate of water and solute absorption by roots. Root injury due to low temperature in the winter is more common in sandy soil than in clay. Soil temperature is also important in the sense that it plays important role in determining the geographical distribution of plants on the earth. Soil temperature is affected by air temperature, the intensity of sunlight, the angles at which sun rays strike on the surface of soil, daily duration of sunlight, the amount of soil moisture and many other factors.

(v) **Soil atmosphere**. In the soil, the spaces left between soil particles are called pore spaces. These spaces contain air. Soil air contains slightly lower proportion of oxygen and higher one of CO_2 than atmospheric air contains. Water logged soils are deficient in oxygen. Normally, plenty of oxygen in the soil is necessary for the life of micro-organisms and other soil inhabitants. It is also necessary in the respiration of underground parts of higher plants. Oxygen content of the soil is also an important factor in seed germination. The germinating seeds respire rapidly and usually they require large amount of oxygen.

(vi) **Soil organisms**. The plants, animals and microbes inhabiting the soils show marked effects on the soil fertility. Decomposing agents, such as, bacteria, fungi, and many others convert dead organic matters into humus, free organic compounds and organic ions and thus make the nutrients available to the plants. Some soil organisms secrete essential or beneficial substances including growth hormones and some of them secrete toxic substances in the soil, which show marked effects on the growth and distribution of plants. Some of the bluegreen algae like *Nostoc*, *Anabaena*, *Cylindrospermum* are beneficial to the higher plants because they fix atmospheric nitrogen into nitrogenous compounds that are utilised by the higher plants. Singh (1961) found that algal films that developed on paddy fields in Uttar Pradesh and Bihar were active nitrogen fixer bluegreen algae. The animals of burrowing habitat also play important role in the soil by turning over the soil. Earthworms increase the fertility of the soil by adding excretary matters to it and also by making it loose. Local distribution of plant communities in different regions also brings about changes in the composition and fertility of the soil in those regions.

PHYSIOGRAPHIC FACTORS

Physiographic factors are those which are introduced by the structure, conformity and behaviour of the earth's surface, by topographic features, such as elevation and slopes, by the geodynamic processes, such as silting and erosion and consequently by local geology. Mountains, hills, valleys etc. result from the irregularities in the earth's surface. These strong topographical reliefs tend to produce marked local climates or microclimates. The summits, for example, are different from the sides of mountains and narrow valleys are different from the open plains. At high altitude, the velocity of wind is high, temperature and air pressure decrease, humidity as well as intensity of light increases. Thus the climatic factors show variations and they become progressively extreme and rapid with increasing altitudes. Major topographic features influence the climate to a considerable extent, for example, the mountain ranges may cause heavy rainfall locally and low rainfall in their lees.

It has been observed that in the northern hemisphere north facing slopes tend to be more adjusted to moist conditions than the south facing ones at similar altitudes. This is so, probably, because of the effects of the solar radiations on the air and soil temperatures and consequently on the relative humidity and evaporation and through them on the local water situation. The duration of sunlight on the south facing slope is longest. The vegetation on north facing slopes receives little or no direct solar radiations. The slope of the soil surface affects the vegetation directly as well as indirectly. The steepness of slope accelerates, the circulation of soil water. The steeper the slopes the more rapid is downward movement of surface water. The water moving over the slopes causes erosion of the top soil and as a result to this vegetations disappear from the areas. Erosion and geodynamic agencies are active in mountain regions and about the sea coasts causing many types of changes in the topography. Such activities often cause formation of new open habitats, both at the sites of erosion and at the places where eroded soil is deposited. Moving sand dune in deserts may be cited as exampale of geodynamic source of physiographic change. The areas subjected to quick and continuous erosion are completely devoid of vegetation.

BIOTIC FACTORS

The biotic factors include the influence of living organisms, both plants and animals, upon the vegetation. Any activity of the living organism which may cause marked effects upon vegetation in any way is referred to as **biotic effect**. The biotic effect may be both direct and indirect. It may be beneficial for the plants in some respects but detrimental in other respects.

The plants live together in a community and influence one another. In the forest there are many plant communities, such as trees, herbs, shrubs, mosses, lichens. These communities interact with one another and adjust according to environmental conditions. Trees cast their shadow on many shade-loving plants which grow around or beneath them. The micro-organisms, such as bacteria, algae, fungi, and viruses affect the life of plants of a given area in many ways. Besides these, the decomposition of dead parts of plant bodies causes significant addition of organic compounds and humus to soil. In this way, the vegetation modifies the habitat to a considerable extent. Similarly, animals which are in close association with plants also affect the plant life in one or several ways. Many animals use plants as their food and for shelter as well. Besides the animals, the man is most significant agent for modifying the vegetation.

The biotic effects modifying the vegetation can be discussed in the following heads :

(1) Interactions between the plants and local animals and man.
(2) Interaction between plants growing in a community.
(3) Interaction between plants and soil micro-organisms.

1. Interaction between Plants and Local animals and man

These can be described under the following heads :

(*i*) Effects of grazing and browsing by animals.
(*ii*) Role of animals in the pollination.
(*iii*) Role of animals in the dispersal of seeds and fruits.
(*iv*) Insects and carnivorous plants.
(*v*) Effects of human activities on vegetation.
(*vi*) Myremecophily.
(*vii*) Miscellaneous effects.

(**i**) **Effects of grazing and browsing**. *Grazing* means eating away of unharvested herbs as forage by animals (Fig 2.7A) as for example, eating away of grasses by goats, whereas *browsing* refers to a similar use of shrubs or trees by animals (Fig. 2.7B), as for example, eating away of leaves and small twigs of Margosa (Neem) by camels. The animals destroy a large part of vegetation by grazing and browsing. Some animals prefer to graze and browse on some particular plant species, *i.e.*, they show selective grazing and browsing,

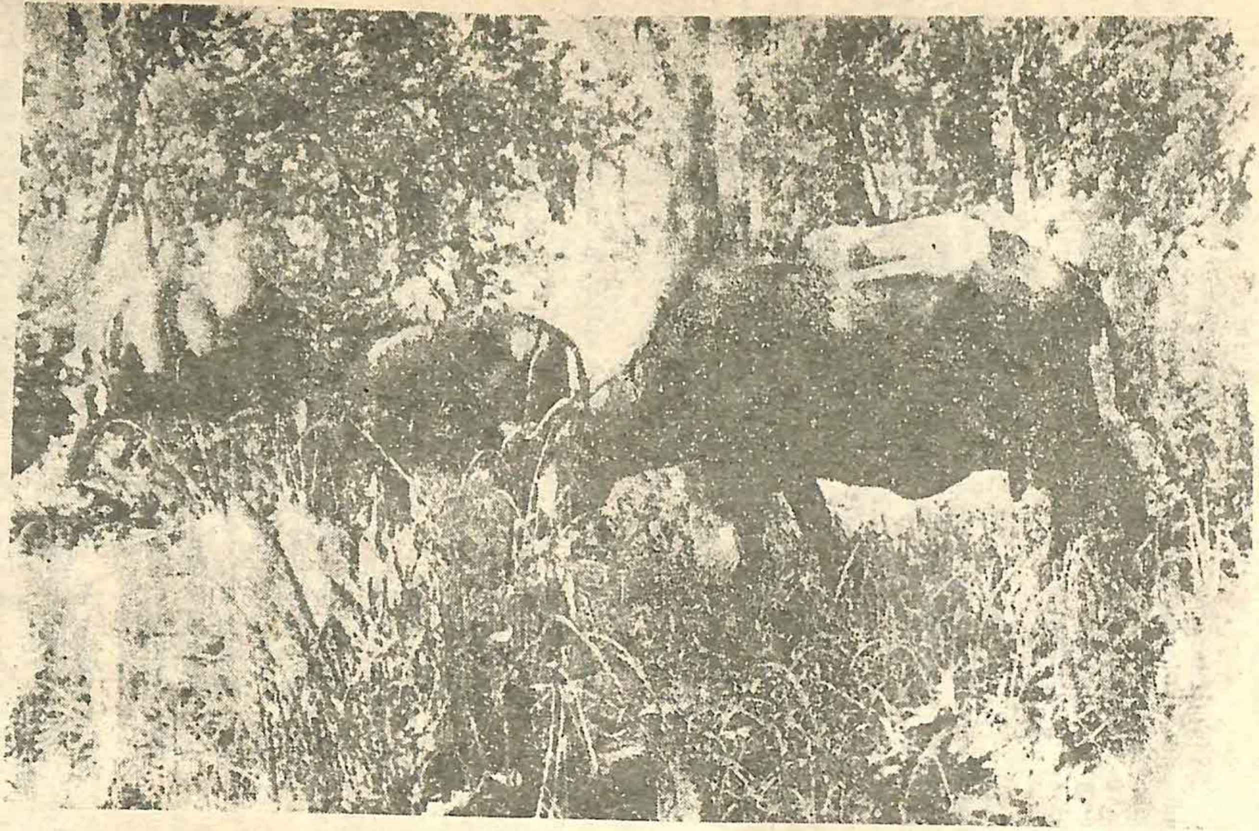


Fig. 2·7A—Grazing of grasses by buffaloes.

e.g., sheep normally prefer forbs, horses and cattle prefer grasses and goats and deer prefer woody and leafy parts of plants. Small annual plants become uprooted and disappear after being grazed. In browsing, taller plants such as trees and shrubs are little affected.

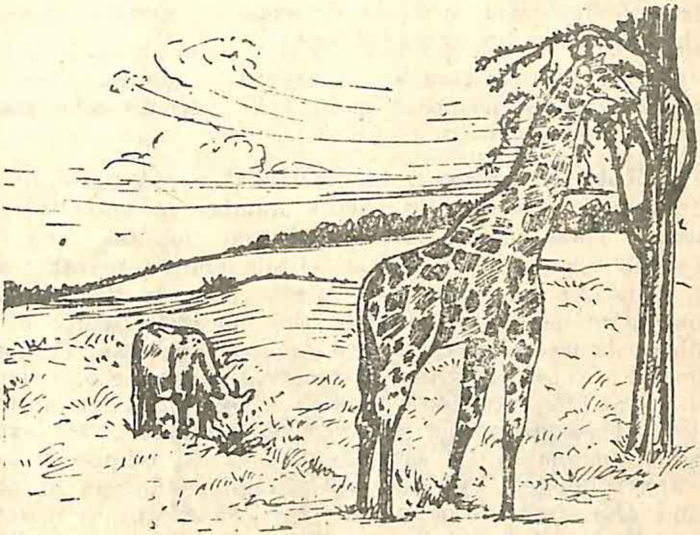


Fig. 2.7B—Grazing and Browsing by animals.

Various other effects of grazing and browsing are summarised briefly in the following points :

(*a*) The grazing and browsing adversely affect the aeration of soil and make it compact and hard and finally render the soil unfit for the growth of trees and shrubs. Forests open to cattle are changed first into shrubby vegetations and finally into grasslands. Excessive grazing and browsing may thus change the pattern of vegetation and finally lead the area to develop into desert. Murphy (1951) is of the opinion that Sahara desert developed as a result of unchecked and excessive grazing by goats, sheep and by introduction of camels in the area. Experimental works near the periphery of Sahara by Kassas (1956) have shown that great many vegetational changes took place when grazing by animals was completely checked. Unrestricted grazing and browsing are the main causes for the eastward spread of desert in the part of Punjab, Delhi and Rajasthan.

(*b*) The grazing and browsing reduce greatly the frequency of photosynthetic organs (leaves and apical green parts of stem) and thus curtail the assimilation.

(*c*) The grazing and browsing reduce the vegetation from the surface of earth to a considerable extent and thus expose the soil for erosion.

(*d*) The most important effect of grazing and browsing is the trampling. In the trampling complete destruction of small and weak annual herbs is caused by the hoofs, paws and feet of animals, but the shrubs and trees are little affected. Usually trampled area becomes inhabited by special type of plants which can withstand the mechanical effect of trampling. These plants propagate vegetatively and are not dependent upon the seed for their propagation. Some grasses, *Heylendia latibrosa*, for example, survive better in the grazed habitats than in non-grazed areas.

(*e*) In grazed pasture and meadows, dung avoiding plants (coprophobic plants) disappear giving place for the colonization of non-coprophilous vegetation.

(ii) **Role of animals in pollination**. A large number of plants depend on insects, birds and a number of animals for their pollination. These plants develop coloured flowers. The flowers possess scents, nectar, sap, edible pollens and many other characteristic structures for attracting insects towards them. Insects, birds and other pollinators visit to the flowers in search of honey and edible pollens. Flowers in the families Rosaceae, Compositae, Leguminosae, Rutaceae, Umbelliferae, Eurphorbiaceae, Cruciferae, Ranunculaceae are pollinated by insects. Some plants are specialized in their pollination by particular type of animals, for example, *Rafflesia* is pollinated by elephants and birds, bilipped flowers of *Salvia* are pollinated by bees, entomophilous flowers of orchids, *Ficus* and *Calotropis* are pollinated characteristically by insects. It is observed that different types of flowers and their pollinators generally live together in the same biotic communities and affect each other's life. R.F. Daubenmire says that "Extreme specialisation is as dangerous in connection with pollination as with other functions in the biological world, for not only must the ranges of two symbionts coincide but also the extinction of the one heralds the doom of the other."

Besides insects, birds, bats and some other animals, man too is taking active part in pollinating artificially one plant with the pollen of some other plant species. The artificial pollination is being used by man for the production of high yielding and disease resistant plant varieties.

(iii) **Role of animals in the dispersal of fruits and seeds**. Many animals, such as birds, bats, monkeys, act as important agents for disseminating the seeds, fruits and spores and thus they play important role in the migration of plants.

The seeds of many plants are very hard. Such seeds along with fleshy parts of fruits are swallowed by animals. While passing through the elementary canals of animals hard seeds are not affected by digestive juices. When the animals leave faecal matter, the uninjured seeds present in it germinate. Passing of seeds through the digestive tracts sometimes facilitates their germination in certain cases. The seeds of tomato, tobacco, guava and many other plants are dispersed in this way.

The hairy, spiny, hooked and sticky fruits and seeds of some plants get entangled with the bodies of birds and other animals and with the clothes of man and are brought to distant places. When the animals sit and clean their bodies at some places these seeds are dropped down there. Seeds and fruits of *Xanthium*, *Andropogon*, *Plumbago*, *Aegle marmelos* are dispersed in this way.

Ants are good agents for transporting oily seeds and small grains of cereals.

(iv) Insects and Carnivorous plants. Semi-autotrophic insectivorous plants, as for example, pitcher plant, *Drosera* (Fig. 2.8 A) *Aldrovanda* (Fig. 2.8B), *Dionaea* (Fig. 2.8C), bladderwort, etc. grow in the habitats which are deficient in nitrogenous compounds. These plants have some specialised organs and mechanisms for trapping and assimilating the preys.

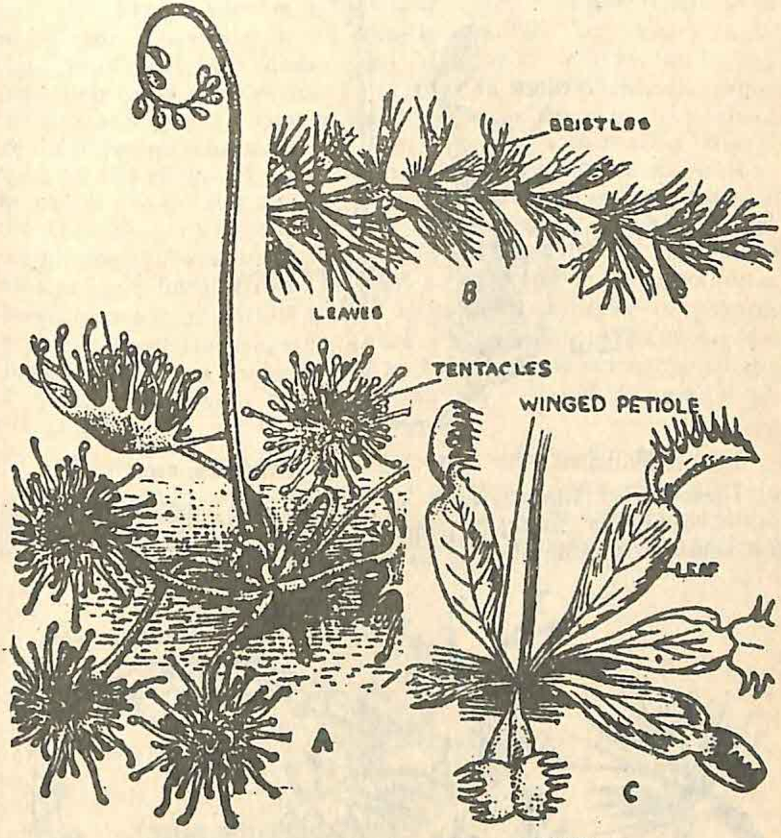


Fig. 2.8 A, B & C—Insectivorous plants
A—*Drosera*,
B—*Aldrovanda*,
C—Venus fly trap (*Dionaea*)

Pitcher plants have leaf pitchers containing liquid and enzymes inside (Fig. 2.9). When the insects are trapped down in the pitcher they are digested and assimilated by it. In *Drosera* spathulate leaves are covered with sensitive glandular hairs which shine in the sunlight and attract insects and small flies. When the insects are entangled in the surface glandular hairs of leaves, digestive enzymes are secreted immediately which kill and digest the bodies of insects. The digested parts of insects are absorbed by the surface cells of the leaves.

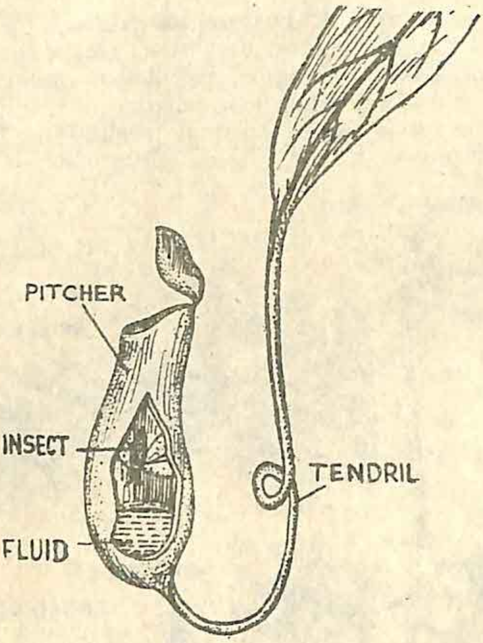


Fig. 2.9—Pitcher plant. A leaf pitcher with insect.

Utricularia (Bladderwort) is an aquatic insectivorous plant which is commonly found in ponds of India. Its bladders catch and digest small swimming aquatic animals (Fig. 2.10).

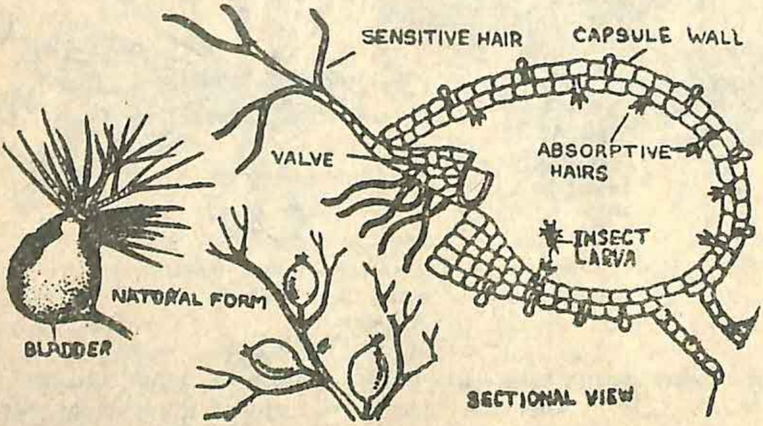


Fig. 2·10—*Utricularia*

(v) Effects of human activities on vegetation. Man affects vegetation in the following ways :

(*a*) By cutting, felling and replanting the forest trees.

(*b*) **Cultivation.** Besides the old methods of cultivation, man has adopted a number of advanced methods for cultivation of plants. Cutting, budding, grafting and other methods used by man are proved beneficial for certain plants. Now at various research stations men are performing cross breeding experiments to evolve new varieties of plants that give high yields and are disease resistant. In cultivation, the destruction of weeds by man eliminates the competition among the plants (Fig. 2·11). Proper spacing of plants during cultivation also checks the competition among them for food.

(*c*) **Fire.** Fire is a biological factor rather than a physical factor because it is mostly caused by man's activity. Lightning initiated fires have destroyed plants and animals since their early appearance on earth. In some countries, especially America and Africa, a lot of work has been done on the effects of fire on different ecosystems. A large body of information has developed on the effects of fire on grasslands and forests as well as on the use of fire in land management. The branch of ecology which deals with the effects of the fire on ecosystem is called "Fire ecology" or Ecopyrology. Plants having ability to withstand fire with little or no damage are referred to as *Pyrophytes*. A number of pyrophytes are known to occur in Siwalik hills. Important examples of pyrophytes are *Cochlospermum religiosa*, *Combretum nanum*, *Grewia sapida* etc. These small plants are supposed to have become permanently dwarfed by annual jungle fires. Pyrophytes are mostly woody plants with thick bark.

Fires caused by man's activity are responsible for complete destruction of vegetation at certain places resulting in temporary or permanent alterations in the characters of vegetations. In some parts of tropics and subtropics, especially in Africa, the burning of grassland has been a regular practice for the last many centuries. Generally in fires the aerial parts of plants are destroyed completely, but their roots, rhizomes or other underground parts

Fig. 2.11—A man scrapping the grasses in the field,

may sometimes remain unaffected which under favourable conditions may grow and produce new plants. Fire generally makes the area suitable for the growth of grasses and thus improves the quality of forage. Post-burn plants are preferred by herbivores. Animals grazing on burnt grasslands are found to gain in weight more rapidly than those grazing on unburnt grasslands. Fire removes harmful plant, and animal parasites and pests.

Litter accumulations physically prevent the healthy production and growth of some plant species in grassland. Fire not only removes the choking litter accumulation but also reduces the organic debris to ash. It affects the productivity by stimulating both the above and below ground growth, increases flowering in forbs and seed production in grasses, increases certain species like legumes and improves nutrient content of the grass lands species. Burning in normal course does not appear to grassland soils adversely and generally improves them. Mineral salts of calcium, magnesium, potassium and phosphorus increase with burning- Excessive burning may reduce the humus content and the fertility of the soil. Soil acidity is increased and erosion is accelerated. Annual burning coupled with continuous heavy grazing will have detrimental effects on the health of grassland. The grazing-burning rotation is very useful in the management of pampas or Savannahs. In the ancient times man used fires to clean forest vegetations also for lightening purposes. Vansteen (1936) is of the opinion that many deserts in the old world are man made. Recent works in Australia by Spech *et al.* (1958); Coaldrabe (1951) and in Canada by Schmidt (1960) have thrown light on the significance of fire in determining the type and composition of plant communities.

(*d*) Man also clears the vegetation for making houses, roads, etc.

(*e*) In ancient times many human invasions took place in India which caused great destruction of vegetation. Alexander (330B.C.), Muslim invasion after 850 A.D., Gori and Gaznavi, and Rajput invasions destroyed dense forests and converted them into deserts. Mohanjodaro and Harappa are examples which are supposed to have become deserted as a result of human invasion. The excavations of Mohanjodaro and Harappa indicate that shrubby plants were abundant in the desert areas of Punjab and Sindh.

(vi) Myremecophily. Sometimes ants take their abode or shelter on some trees such as Mango, Litchi, Jamun, South American *Acacia* (*Acacia sphaerocephala*) (Fig. 2.12) and so on. These ants act as body guards of the plants against any disturbing agent. In lieu of this defence, the plants provide food and shelter to these ants. This phenomenon is known as myremecophily.

(vii) Miscellaneous effects. The animals also affect the plant life in many other ways. Some animals, as for example, barkeater, rodents, may kill a large number of trees. Juice sucking insects, woodpeckers, bud eating birds, sparrow, squirrel and other animals cause great harm to the vegetation. Elephants detach the branches of the trees and sometimes uproot the gigantic trees.

The insects, birds, squirrels, mice and rodents eat abundant seeds. Some animals eat and destroy seeds at the sowing time. Fishes, ducks and other aquatic animals depend upon aquatic plants for food and shelter.

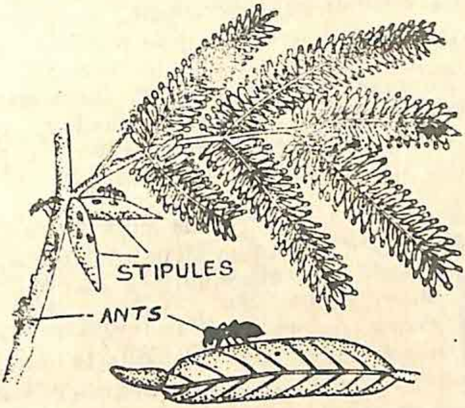


Fig. 2.12—Myremecophily.

Termites are chief agents for destroying seeds, seedlings and standing crop plants in the fields. Termites and their termitaria serve important ecological function in African Tropical wet-dry soils which has been appreciated and utilized by indigenous African agriculturists in northern Malawi and neighbouring south-western Tanzania. Howard W. Mielke, (Tropical Ecology. Vol. 19, No. 1, 1978) has highlighted the importance of termites and termitaria in Tropical wet dry Africa. Termites and termitaria contribute to the development of soils. The enhancement of the mineral content in termite mounds as compared to adjacent soils has been observed by many workers (Hesse, 1955; Stoops, 1964; Lee and Wood, 1971; Watson, 1975; Milne, 1947; Watson, 1969; Bouillon, 1970). This enhancement in mineral contents of termite mounds has been attributed to the interaction of several factors :

(1) Termite behaviour in aggregating finer soil particles within their mounds; (2) termite behaviour in collecting and storing significant amounts of plant matter and accompanying base minerals in their mounds, and (3) relatively low rate of leaching occurring on the mounds due to their dome shape and concomitant propensity to shed water. Nitrogen fixing bacteria have been found associated with some species of termites and as a result of this association some species of termites facilitate the fixation of significant amounts of nitrogen. Termites are important food in the human diet of Africans of the Tropical dry-wet climatic regime· Termitaria soils are used as a raw material for the production of cement mortar plaster and bricks and are used in the construction of everything from buildings to roads (Lee & Wood, 1971). Termites and shifting cultivation also provide nutrients and habitats for migratory Pataearctic birds.

2. Interactions between plants growing in a community

Various plants in a community react with one another in several ways for :

(*i*) Water,
(*ii*) Essential soil minerals and organic compounds, and
(*iii*) Light and air.

The taller plants modify the habitat for the plants growing around and underneath them by casting shadow, protecting them from injuries by strong wind, by increasing the atmospheric humidity, and by determining the humus content of the soil.

The most interesting instances of interactions among plants growing in a community are as follows :

(*i*) Action of lianas ;
(*ii*) Effects of some epiphytes ;
(*iii*) Effects of parasitic plants.

(i) Action of lianas. Lianas are woody vascular plants growing on the ground, maintaining, more or less, autotrophic mode of life and growing upward taking support of some trees and other objects. The woody stems of these plants have well developed alternating vertical columns of secondary xylem and parenchymatous tissues which enable them to twist around the supporting objects (Fig. 2.13). In tropical evergreen forest, lianas grow at the top of the trees and form the top layer of the forest canopy. This habit enables these lianas to get sufficient light. The lianas affect other plants also because they cast their shadow and check the light from reaching to the plants of lower storeys.

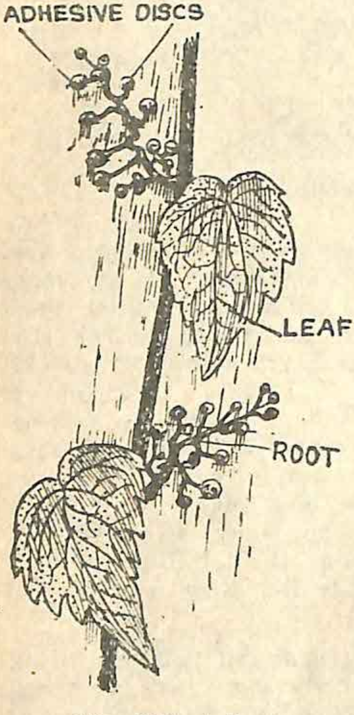


Fig. 2.13—A liana

(ii) Effects of some epiphytes. The epiphytes grow on the leaves and stems of other plants. They are autotrophic and are dependent on other plants only for support. Epiphytes differ from parasites in not taking food from the hosts and also differ from lianas in not having any permanent connection with the soil. The examples of epiphytes may be found in the families Orchidaceae, Asclepiadaceae, Bromeliaceae, Cactaceae, etc. *Dischidia*, *Tillandsia* are most common examples. Epiphytes are found in humid climates. The two main problems for these plants are (*a*) maximum absorption of water from the atmosphere and from the bark surface of the supporting plant and (*b*) maximum economy in the water consumption. These plants develop two types of roots, namely the aerial and clinging roots. The aerial roots are thick and have specialised thin walled porous absorptive tissue, the 'velamen' on their surface. These roots absorb rain water and moisture from the atmosphere. The clinging roots fix the epiphytes on the surface of supporting plants. Because the epiphytes are autotrophic, they do not affect the supporting plants to any considerable extent.

(iii) **Effects of parasitic plants.** Some plants are heterotrophic and are dependent on other plants for their food requirements. They are called parasites. These are of the following two types :

(*i*) Ectoparasites (external); and
(*ii*) Endoparasites (internal).

The endoparasites are more destructive than the ectoparasites. Because the parasites take their food from host plants, they check the growth and ultimately cause the death of their hosts. *Cuscuta*, *Loranthus*, *Orobanche*, *Rafflesia*, and sandal wood tree (*Santalum album*) are important parasitic angiosperms which may grow either on roots or on stems and sometime even on the leaves of the higher plants. The parasites may be either obligate or facultative.

Cuscuta (Fig. 2.14 A & B) is an obligate stem parasite on *Acacia*, *Zizyphus* and a number of other angiospermic plants.

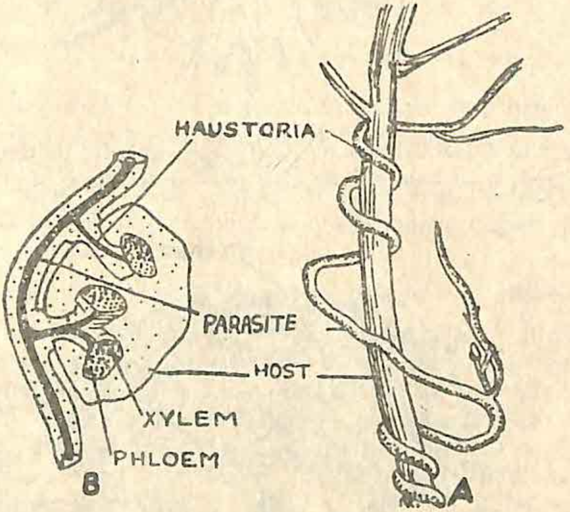


Fig. 2.14A—*Cuscuta* on the host. B—T.S. of host along with *Cuscuta*

Loranthus is a partial stem parasite on Mango. *Orobanche* grows very commonly on the roots of crucifers and solanaceous plants as obligate roots parasite (Fig. 2.15 A & B). Other important parasites are *Rafflesia* on the roots of *Vitis* (Fig.2.16), *Viscum album* on coniferous trees (Fig.2.17). *Striga*, one of the smallest angiospermic parasites grows on the grasses, *Arceuthobium minutissimum*, an interesting smallest parasitic dicot, is an obligate stem parasite of *Pinus excelsa*.

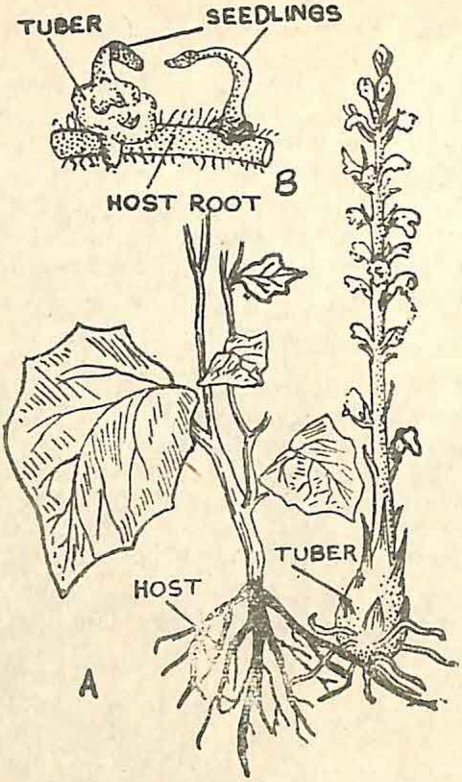


Fig. 2.15 A & B *Orobanche*. A—Parasite growing on the root of brinjal. B—A root of host with growing seedlings of parasite.

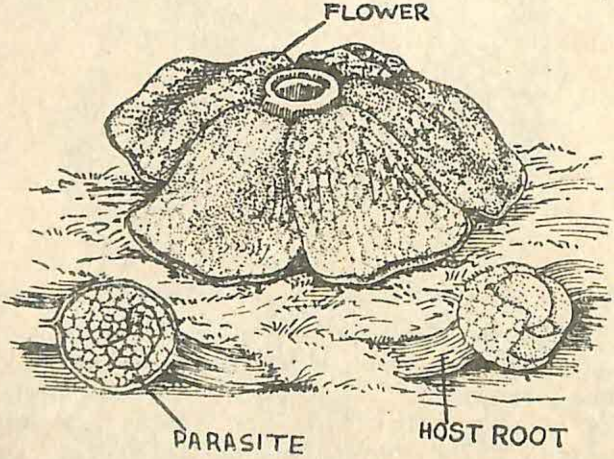


Fig. 2.16--*Rafflesia* on the root of *Vitis*.

Besides angiospermic parasites, fungi and bacteria are also known to parasitise plants and cause several destructive diseases in them.

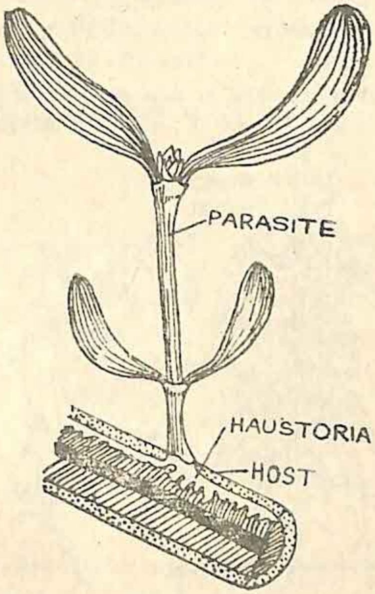


Fig. 2.17—Mistletoe (*Viscum*), a partial stem parasite

Puccinia graminis is a parasitic fungus causing rust diseases in wheat. Mildews, smuts, white rust, damping off, and blight diseases are generally caused by parasitic fungi.

Many algae are also known to parasitise several plants and cause diseases in them. Most common example is *Cephaleuros* which is found on a number of angiosperms.

3. Interaction between plants and micro-organisms

Various kinds of bacteria, protozoa, algae, fungi, worms, nematodes and other soil microbes act as important agents which alter the physical and chemical properties of the soils, increase or decrease their fertility. These changes in the soil properties have great impact on the nature and growth of vegetation. Very often soil microbes such as nematodes, bacteria and fungi cause many diseases in the underground parts of plants. Viruses too cause several mosaic and other diseases in many plants, as for exmaple, the curling of tomato leaves, mosaic patterns in papaya and lady's finger (Bhindi), bean mosaic, tobacco mosaic etc.

Some microbes secrete growth stimulating substances in the soil which induce the growth of plants.

Besides above effects, the soil microorganisms show symbiotic activities and many soil fungi form mycorrhizal association with the roots of higher plants. These two phenomena, *i.e.*, symbiosis and mycorrhizal associations, are described below.

Symbiotic influence. Some soil microbes live in close association with plants, both benefiting from each other. In this association both the organisms are interdependent and they do not harm each other. This mutual relationship between two organisms is known as symbiosis and the interdependent organisms are called symbionts.

Many cases of symbiosis in plants are known. The nodulated roots of legumes contain nitrifying bacteria (*Rhizobium*) (Fig.2.18). These bacteria fix atmospheric nitrogen into nitrogenous compounds and benefit the legumes by supplying nitrogenous compounds in usable form. The leguminous plants in return provide nutrients, water and shelter to bacteria. When the roots of these plants die, decomposition of dead remains takes place in which the nitrogenous substances are converted into nitrite, nitrate and ammonium ions that are absorbed by the plants. *Nostoc* and *Anabaena* living symbiotically in the coralloid roots of *Cycas* also fix atmospheric nitrogen.

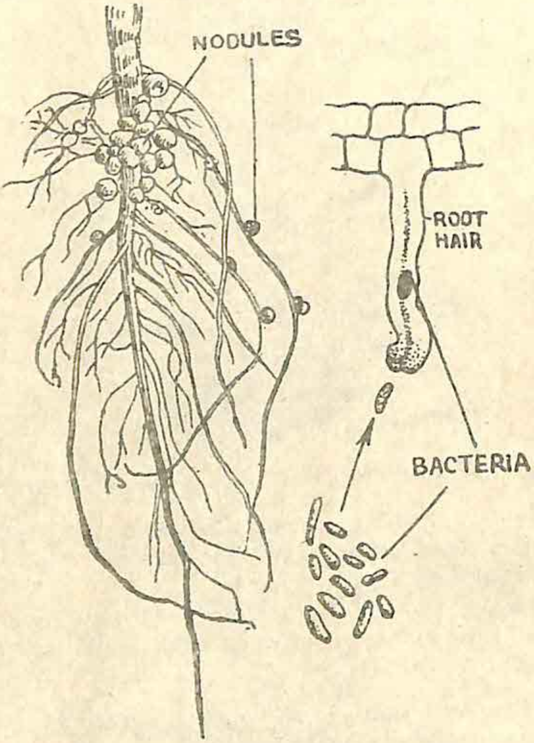


Fig.2.18—A nodulated root, soil bacteria and infected root hair

Lichens also show symbiosis. These are synthetic plants in which algae and fungi live symbiotically. Generally, the algal component belongs to myxophyceae and fungal components are ascomycetous or sometimes basidiomycetous forms. In this association, algal component fixes the atmospheric nitrogen, prepares food and supplies nutrients to its fungal counterpart. Fungal component gives support to the algal component. It also saves algae from desiccation because of its sponginess and high water holding capacity.

Mycorrhizal association. Sometimes fungi grow on the surface or inside the roots of higher plants. They are called mycorrhizae. Micorrhizae are of two types.

(*i*) *Ectotrophic mycorrhiza*. Fungus lives on the surface of roots of higher plants (Fig. 2.19).

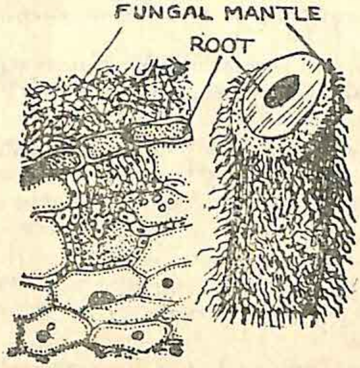


Fig. 2.19—Ectotrophic mycorrhiza or the root fungus

(*ii*) *Endotrophic mycorrhiza*. Fungus penetrates the deeper tissues of the roots and rhizomes (Fig. 2.20).

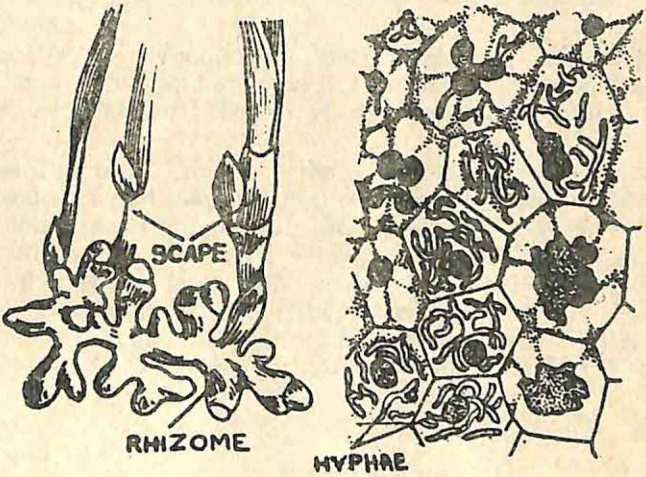


Fig. 2.20—A swollen rhizome with endophytic mycorrhiza

The roots with mycorrhizae are unbranched and without root-caps and root hairs. Fungal hyphae in this association act like root hairs, absorb water and minerals from the soil and supply them to the roots. The roots in return provide food and shelter to these mycorrhizae. It has been estimated that some species of plants in about 80% families of seed plants have mycorrhizal association. Blue berries can not grow without mycorrhiza. Orchid seedlings do not develop properly unless they become infected with mycorrhizae.

Recent researches have shown that mycorrhizae play very important role in the root tissues. They regulate acidity and sugar content in the root tissues and enable the roots grow vigorously.

Questions

1. What is environment ? What are various envirnmental factors which influence the plant life ?
2. What is effect of light on vegetation ? What is its significance to plants ?
3. What is effect of biological factors on plants ?
4. Write short notes on :

   Biotic factors, Mycorrhiza, Soil profile, Soil water, Effect of wind on vegetation.

3

ECOSYSTEM

An organism is always in the state of perfect balance with the environment. The environment literally means the surroundings. The environment refers to the things and conditions around the organism which directly or indirectly influence the life and development of the organisms and their populations. Organisms and environment are two non-separable factors. Organisms interact with each other and also with the physical conditions that are present in their habitats. "The organisms and the physical features of the habitat form an ecological complex or more briefly an ecosystem." (Clarke 1954).

The concept of ecosystem was first put forth by A.G. Tansley (1935). Ecosystem is the major ecological unit. It has both structure and function. The structure is related to species diversity. The more complex is the structure, the greater is the diversity of the species in the ecosystem. The function of ecoystem is related to the flow of energy and cycling of materials through structural components of the ecosystem.

According to Woodbury (1954), ecosystem is a complex in which habitat, plants and animals are considered as one interesting unit, the materials and energy of one passing in and out of the others.

According to E. P. Odum, the ecosystem is the basic functional unit of organisms and their environment interacting with each other and with their own components. An ecosystem may be conceived and studied is the habitat of various sizes, *e.g.*, one square metre of grassland, a pool, a large lake, a large tract of forest, balanced aquarium, a certain area of river and ocean. All the ecosystems of the earth are connected to one another, *e.g.*, river ecosystem is connected with the ecosystem of oceans, and a small ecosystem of dead logs in a part of large ecosystem of a forest. A complete self-sufficient ecosystem is rarely found in nature but situations approaching self-sufficiency may occur.

Components of ecosystem. According to Odum, all ecosystems; terrestrial or aquatic, from a purely functional or trophic (nutrition) point of view have the following two basic components :

(*i*) *Autotrophic component*, and

(*ii*) *Heterotrophic component.*

The autotrophic component fixes the radiant energy of sun and manufactures food from simple inorganic substances.

The heterotrophic component takes food from autotrophic, rearranges it and finally decomposes the complex organic materials into simple inorganic forms.

In the ecosystems, the autotrophic and heterotrophic components are arranged in layers or strata. The autotrophic metabolism is greatest in the upper stratum where maximum light is available.

In the forest ecosystem, the autotrophic metabolism is maximum in the canopy and in the water ecosystem it is in the surface water where mostly autotrophs are concentrated because of maximum availability of light. The heterotrophic activity is maximum in the lower layer where organic matter accumulates. In the land ecosystems the heterotrophic stratum is the top layer of soil and in aquatic ecosystem it is the bottom sediments.

The ecosystems have structures also and they contain both **non-living** or **abiotic substances** such as water, soil, air and energy and **living** or **biotic components** such as plants, animals and microbes. According to Odum, ecosystems generally include four categories of basic structural components :

(1) Non-living or Abiotic components
(2) Producers, mainly green plants
(3) Consumers, almost exclusively animals
(4) Decomposers, mainly bacteria and fungi.

Some authors have used a term *reducers* for decomposers. Clarke has recognised *transformers* as the fifth structural component of ecosystems.

Abiotic Components

Ecological relationships are manifested in physico-chemical environment. Abiotic component of ecosystem includes basic inorganic elements and compounds, such as soil, water, calcium, oxygen, carbonates, phosphates and a variety of organic compounds (by product of organic activity or death). It also includes such physical factors and gradients as moisture, wind currents and solar radiation. Radiant energy of sun is the only significant energy source for any ecosystem. The amount of non-living components, such as phosphorus, nitrogen etc. that are present at any given time, is known as standing state or standing quantity.

Biotic Components

Producers (Autotrophic elements). The producers are the autotrophic elements—chiefly green plants. They use radiant energy of sun in photosynthetic process whereby carbon dioxide is assimilated and the light energy is converted into chemical energy. The chemical energy is actually locked up in the energy rich carbon compounds. Oxygen is evolved as byproduct in the photosynthesis. This is used in respiration by all living things. Algae and other hydrophytes of a pond, grasses of the field, trees of the forests are examples of producers. Chemosynthetic bacteria and carotinoids bearing purple bacteria that also assimilate CO_2 with the energy of sunlight but only in the presence of organic compounds, also come in the category.

The term producer is misleading one because in an energy context, producers produce carbohydrate and not energy. Since they convert or transduce the radiant energy into chemical form, E.J. Kormondy suggests better alternative terms *'converters'* or *'transducers'*. Because of wide use the term producer is still retained.

Consumers. Those living members of ecosystem which consume the food synthesized by producers are called consumers. Under this category are included all different kinds of animals that are found in an ecosystem. There are different classes or categories of consumers, such as,

(*a*) Consumers of the first order or primary consumers,
(*b*) Consumers of the second order or secondary consumers,
(*c*) Consumers of the third order or tertiary consumers, and
(*d*) Parasites, scavengers and saprobes.

(*a*) *Primary consumers.* These are purely herbivorous animals that are dependent for their food on producers or green plants. Insects, rodents, rabbit, deer, cow, buffalo, goat are some of the common herbivores in the terrestrial ecosystem, and small crustaceans, molluscs etc. in the aquatic habitat. Elton (1939) named herbivores of ecosystem as "Kee industry animals". The herbivores serve as the chief food source for carnivores.

(*b*) *Secondary consumers.* These are carnivores and omnivores. Carnivores are flesh eating animals and the omnivores are the animals that are adapted to consume herbivores as well as plants as their food. Examples of secondary consumers are sparrow, crow, fox, wolves, dogs, cats, snakes etc.

(*c*) *Tertiary consumers.* These are the top carnivores which prey upon other carnivores, omnivores and herbivores. Lions, tigers, hawk, vulture, etc. are considered as tertiary or top consumers.

(*d*) Besides different classes of consumers, the parasites, scavengers and saprobes are also included in the consumers. The parasitic plants and animals utilize the living tissues of different plants and animals. The scavengers and saprobes utilize dead remains of animals and plants as their food.

Decomposers and transformers. Decomposers and transformers are the living components of the ecosystem and they are fungi and bacteria. Decomposers attack the dead remains of producers and consumers and degrade the complex organic substances into simpler compounds. The simple organic matters then are attacked by another kind of bacteria, *transformers* which finally change these organic compounds into the inorganic forms that are suitable for reuse by producers or green plants. The decomposers and transformers play very important role in maintaining the dynamic nature of ecosystems.

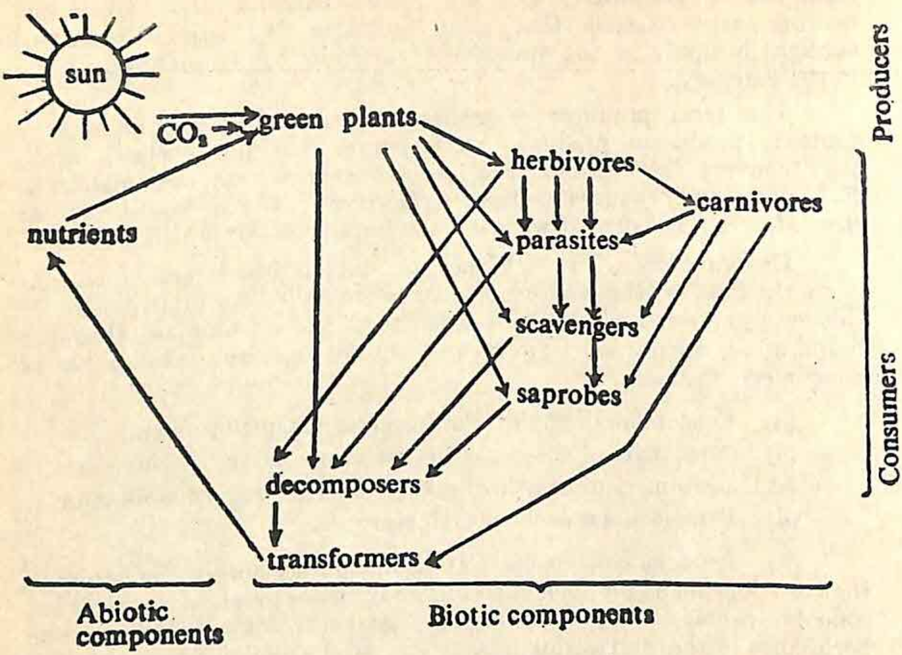


Fig. 3·1. Different components of ecosystem.

Fundamental steps in the operation of Ecosystem

The principal steps in the operation of ecosystem are as follows :

(1) Reception of radiant energy of sun.

(2) Manufacture of organic materials from inorganic ones by producers.

(3) Consumption of producers by consumers and further elaboration of consumed materials.

(4) After the death of producers and consumers, complex organic compounds are degraded and finally converted by decomposers and converters into such forms as are suitable for reutilization by producers.

The principal steps in the operation of ecosystem not only involve the production, growth and death of living components but also they influence the abiotic aspects of habitat.

It is now clear that there is a transfer of both energy and nutrients from producers to consumers and finally to decomposers and transformer level. In this transfer there is not a progressive decrease of energy but nutrient component is not diminished and it shows cycling from abiotic to biotic and *vice versa*.

The flow of energy is unidirectional. The two ecological processes—energy flow and mineral cycling—which involve inter-action between biotic and abiotic components lie at the heart of ecosystem dynamics. The principal steps and components of ecosystem are illustrated in figure 3.1.

MAJOR ECOSYSTEMS (BIOMES)

According to Whittaker, R.H. (1970), the major type of community, conceived in terms of physiognomy, on a given continent is a *Biome* or *Formation*. 'Biome' is used when the concern is with both plants and animals and formation' is used when the concern is with plant communities only. These are the products of interaction of regional climate with biota and substrate. A biome is a grouping of terrestrial ecosytems on a given continent that are similar in vegetation structure (physiognomy), in the major features of environment to which this structure is a response and in some characteristics of their animal communities. The biome concept which is most widely applied to land ecosystems can also be applied in aquatic environment to such zones as the world-wide structural types defined by major kinds of organisms.

In the broadest sense there are two major types of ecosystems namely terrestrial and aquatic.

Terrestrial ecosystem operates on the land while the aquatic system operates in the aquatic habitat (Fig. 3.2).

Terrestrial ecosystem can further be divided into the following types :

(1) Forest ecosystem

(2) Grassland ecosystem

(3) Desert ecosystem

(4) Artificial ecosystems which are man made, as for example, crop fields and gardens.

On the basis of salt contents in water, aquatic ecosystems can be divided into the following two types of minor ecosystems :—

(1) Fresh water ecosystems

(2) Marine or oceanic ecosystems

The fresh water ecosystems include pond ecosystem, lake ecosystem, river ecosystem and spring ecosystem.

SOME EXAMPLES OF ECOSYSTEMS

Pond and lake as Ecosystems

Pond is a fresh water ecosystem in which, like other ecosystems, there are two main components :

(A) Abiotic components

(B) Biotic components

(A) Abiotic components. Abiotic component of pond consists of water, dissolved minerals, oxygen and carbon dioxide. Solar radiations are the main source of energy.

(B) **Biotic components.** It includes the following :

(*i*) Producers

(*ii*) Consumers

(*iii*) Decomposers and transformers.

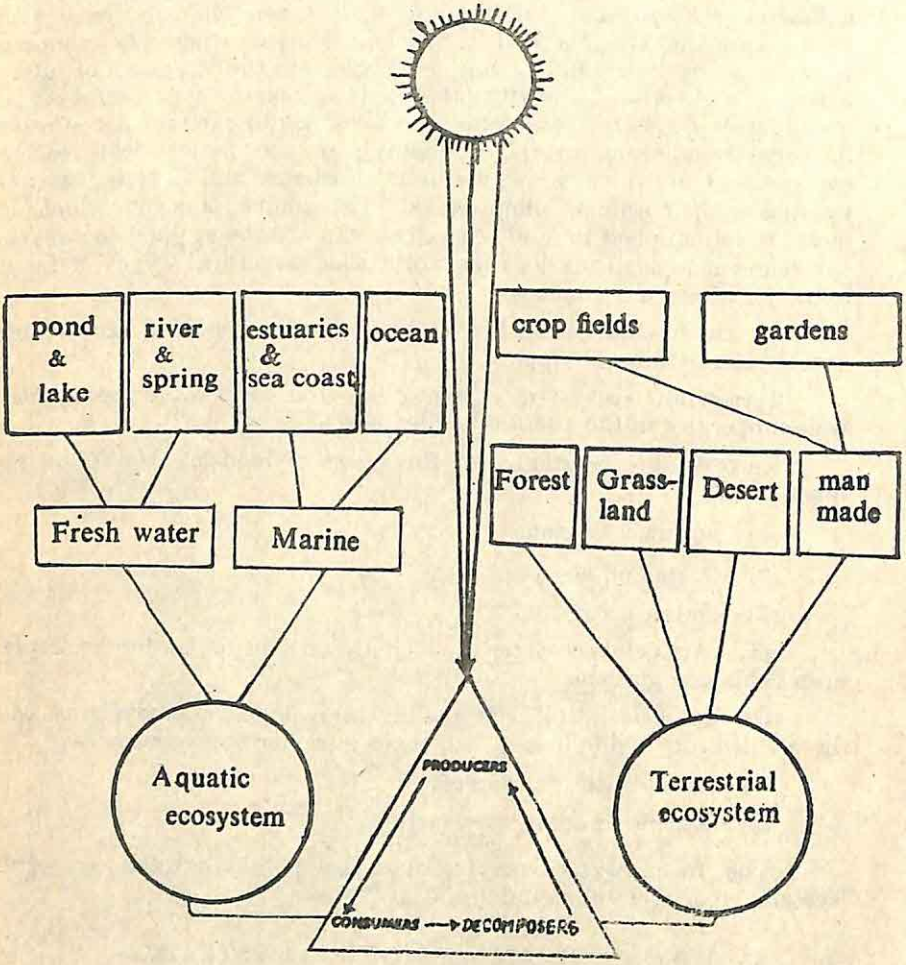


Fig. 3.2—Different types of ecosystem.

On the basis of water depth and type of vegetation and animals there may be three zones in a lake or pond : *littoral*, *limnetic* and *profundal*. The littoral zone is the shallow water region which is usually occupied by rooted plants. The limnetic zone ranges from the shallow to the depth of effective light penetration and associated organisms are small crustaceans, rotifers, insects, and their larvae and algae. The profundal zone is the deep water parts where there is no effective light penetration. The associated organisms are snails, mussels, crabs and worms. (**Fig. 3.3a**)

(i) **Producers**. The main producers in a pond ecosystem are algae and other aquatic plants, such as *Azolla*, *Hydrilla*, *Potamogeton*, *Pistia*, *Wolffia*, *Lemna*, *Eichhornia*, *Nymphaea*, *Jussiaea* etc. These are either floating or suspended or rooted at the bottom. The green plants convert the radiant energy into chemical energy through photosynthesis. The chemical energy stored in the form of food is utilised by all the organisms. Oxygen evolved by producers in photosynthesis is utilised by all the living organisms in respiration.

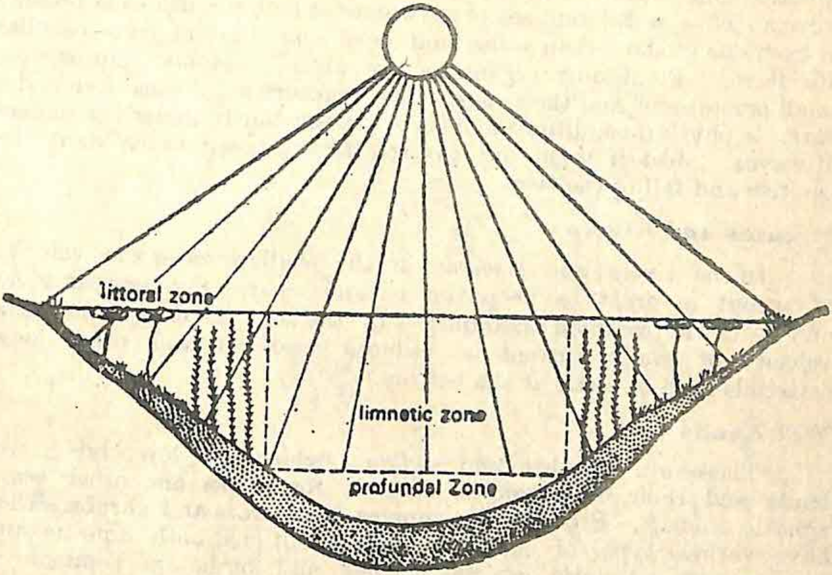


Fig. 3.3*a*—Different zones of a fresh water pond.

(ii) **Consumers**. In a pond ecosystem, the primary consumers are tadpole larvae of frogs, fishes and other aquatic animals which consume green plants and algae as their food. These herbivorous aquatic animals are the food of secondary consumers. Frogs, big fishes, water snakes, crabs are secondary consumers. In the pond, besides the secondary consumers, there are consumers of highest order, such as water-birds, turtils, etc.

(iii) **Decomposers and Transformers**. When aquatic plants and animals die a large number of bacteria and fungi attack their dead bodies and convert the complex organic substances into simpler inorganic compounds and elements. These micro-organisms are called *decomposers*. The chemical elements liberated by decomposers are again utilized by green plants in their nutrition (Fig. 3.3*b*).

Ocean as an ecosystem

The oceans constitute nearly 70 per cent of the earth's surface. The sea has unusual stability in temperature, salinity and gaseous content. The upper portion of the oceanic region through which light penetrates is called euphotic zone. The region of the ocean below the euphotic zone (below 200 metres) is called *benthal*. It is also known as aphotic zone. This zone is completely free of photosynthetic organisms. Thus, a different set of environment and conditions is present in each one of the ocean zones and each zone has its own peculiar life form. Planktonic organisms are algae, diatoms, protozoans, small crustaceans and their eggs. The seashore organisms live under variable physical conditions and they are constantly under the impact of waves. Most of them are covered and exposed twice daily by the rise and fall of the tides.

Streams and Rivers

In the rivers and streams in the shallow water the velocity of current is great to keep the bottom clear. Filamentous algae and fishes are common examples. In the zone of deep water the velocity of water current is reduced and silt and other loose materials tend to settle at the bottom.

Wet Lands

These are marshes and swamps which are low lying wet lands and their ecosystem is suitable for ducks and other semi-aquatic animals. Swamps also support large trees and shrubs. They have various types of environmental conditions, both aquatic and semi-aquatic. Aquatic insects, reptiles and birds are common in such regions.

Forest as an Ecosystem

Forest ecosytem is the best example of a terrestrial ecosystem. Like other ecosystems, there are two main components of forest ecosystem :

(A) Abiotic component
(B) Biotic component.

(A) Abiotic component. In a forest ecosystem soil, moisture, air and sunlight form the abiotic or physical component.

(B) Biotic component. There are three important classes of biotic components :

1. Producers
2. Consumers
3. Decomposers and transformers.

1. Producers. All the green plants of a forest are producers. They are the main sources of food for all the animals. There are several layers of vegetation in the forest. The plants of top stratum are angiospermous and gymnospermous trees. These plants utilize radiant energy of sun to a greatest extent. Below the level of trees there is layer of shrubs which consume light energy of low intensity coming through trees. Just below the shrubs there are grasses, herbs, lichens and mosses. These also manufacture food. These plants get least light.

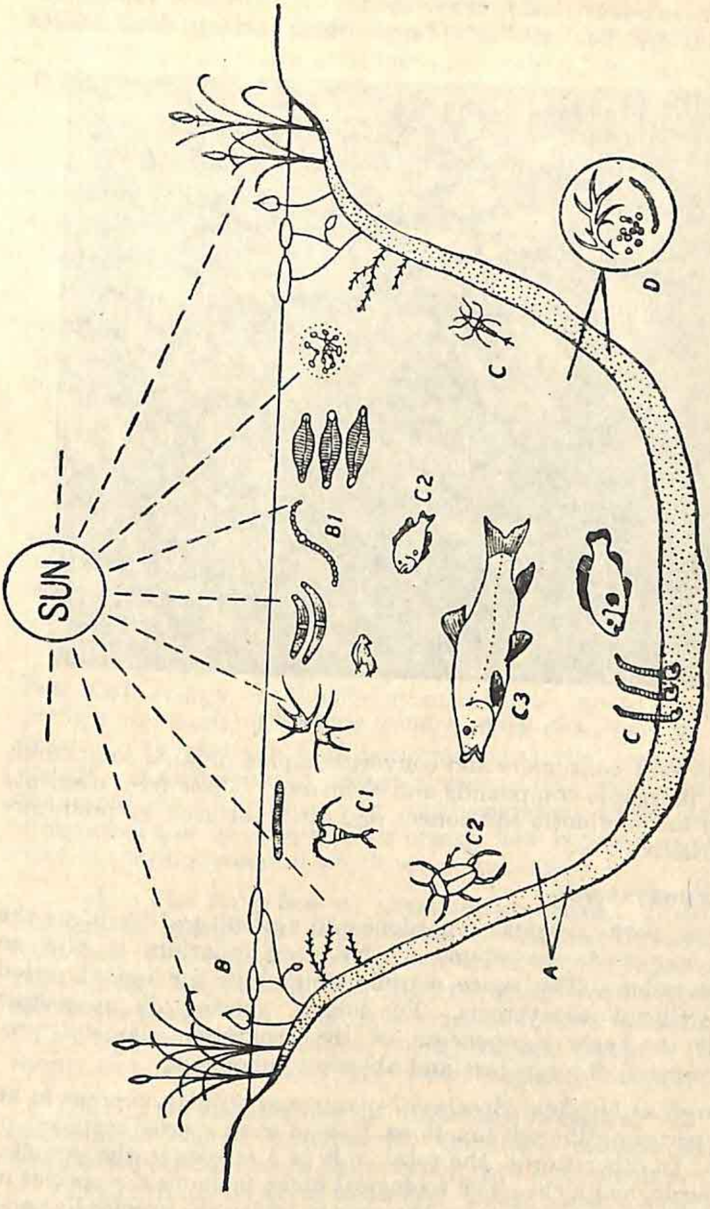


Fig. 3.3b—A pond ecosystem.
A—Abiotic component; B and B1—Producers; C1—Primary consumers (herbivores); C2—Secondary consumers; C3—Tertiary consumers; D—Decomposers—saprophytic bacteria and fungi.

2. **Consumers**. There are a number of consumers in an old dense forest. Consumers of first order in the forest are grasshoppers, rabbit, deer, monkey, birds and many other wild herbivorous animals which utilize plants directly as their food (Fig. 3.3 C). Secondary consumers are wolves, pythons, jackals etc. which consume the flesh of herbivores. Lion, tiger, hawks are the consumers of top level.

3. **Decomposers and transformers.** These are micro-organisms, chiefly bacteria and fungi which attack dead bodies

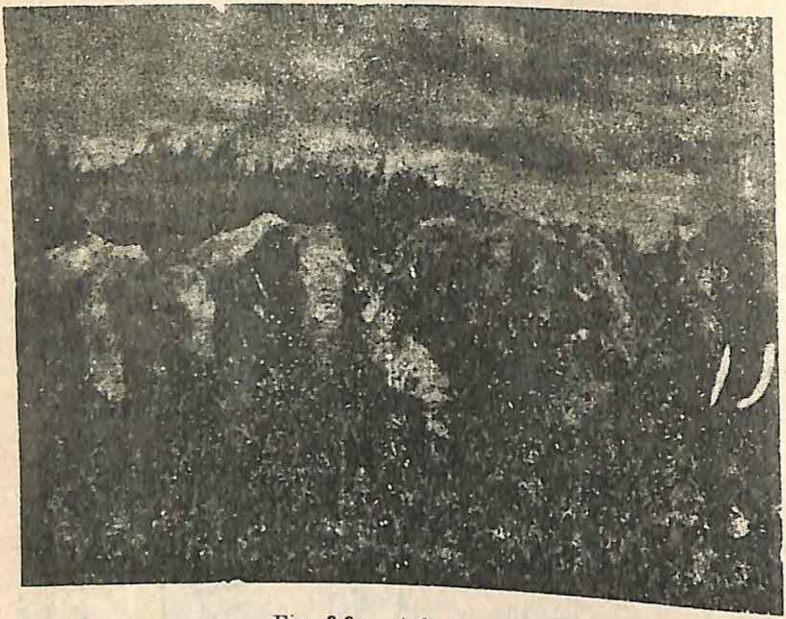


Fig. 3·3 c—A forest ecosystem.

of producers and consumers and convert complex organic compounds into simpler inorganic compounds and elements. These free elements again return to the abiotic component and are re-utilised by producers in their nutrition.

Artificial Ecosystems

Gardens, parks, vegetable gardens and agricultural lands are the artificial or man-made ecosystems. A balanced aquarium is also an artificial ecosystem. The space capsule which lasts for limited period is also an artificial ecosystems. For longer journey on spacecraft includes all the basic components of the ecosystem, namely, producers, consumers, decomposers and abiotic components.

Ecological Niches. Species of plants and animals present in an ecosystem perform different functions. Role of each species is spoken of as its niche. In other words, the total role of a species in the community is the ecological niche. The ecological niche includes the species of organisms, environmental factors, the area in which the species live and the specialization of species population within a community. Every population has an ecological niche, which determines the structure and adaptation of that population. Ecological niche is not a simple concept but it relates the concepts of population and community. The niche is the property of the community which represents the place of the population in the community structure. Different communities in ecosystem characterised by similar environments are often similar in their structure and they may contain one or more niches that are essentially identical. The adaptations of population inhabiting these niches may also be similar, even though they are entirely unrelated.

Odum (1971) has classified the ecolgical niches into following types :

(*i*) **Habitat niches**. Concerned with habitat of the organisms.

(*ii*) **Trophic niches**. Related to physiological modifications.

(*iii*) **Geographical niches**. Related to geographical modifications.

Nature of energy

Energy has been defined as the capacity to do work. It exists in various forms. The forms of energy that are of the greatest significance to the living organisms are mechanical, chemical, radiant and heat energy.

The source of energy required by all living organisms is the chemical energy of their food. The chemical energy is obtained by the conversion of the radiant energy of sun. The radiant energy is in the form of electromagnetic waves which are released from the sun during the transmutation of hydrogen to helium. The chemical energy stored in the food of living organisms is converted into potential energy by the arrangement of the constituent atoms of food in a particular manner.

Mechanical energy exists in two forms : potential and kinetic. Potential energy is the energy at rest (*i.e.*, stored energy) capable of performing work. Kinetic energy is the energy of motion (free energy). It results in work performance at the expense of potential energy. Conversion of potential energy into kinetic energy involves the imparting of motion. In any ecosystem there should be unidirectional flow of energy. This energy flow is based on two important laws of thermodynamics which are as follows :

(1) **The first law of thermodynamics**. It states that the amount of energy in the universe is constant. It may change from one form to another, but it can neither be created nor destroyed. Light energy can be neither created nor destroyed as it passes through the atmosphere. It may, however, be transferred into another type of energy, such as chemical energy or heat energy. These forms of energy can be transformed into electromagnetic radiation.

(2) **The second law of thermodynamics**. It states that non-random energy (mechanical, chemical, radiant energy) cannot be changed without some degradation into heat energy. The change of energy from one form to another takes place in such a way that a part of energy assumes waste from (heat energy). In this way, after transformation the capacity of energy to perform work is decreased. Thus, energy flows from higher to lower level.

Main socurce of energy is sun. Approximately 57% of sun energy is absorbed in the atmosphere and scattered in the space. Some 35% is expanded to heat water and land areas and to evaporate water. Of the approximately 8% of light energy striking plant surface, 10% to 15% is reflected, 5% is transmitted and 80 to 85% is absorbed; and an average of only 2% (0.5 to 3.5%) of the total light energy striking on a leaf is used in photosynthesis and rest is transformed into heat energy.

Energy flow in ecosystems. Living organisms can use energy in several forms : *radiant* and *fixed energy*. Radiant energy is in the form of electromagnetic waves, such as light. Fixed energy is potential chemical energy bound in various organic substances which can be broken down in order to release their energy content.

Organisms that can fix energy from inorganic sources into organic molecules are called autotrophs. Organisms that cannot obtain energy from abiotic source but depend on energy-rich organic molecules synthesised by autotrophs are called heterotrophs. Those that obtain energy from living organisms are called consumers and those that obtain energy from dead organisms are called decomposers.

When the light energy falls on the green surfaces of plants, a part of it is transformed into chemical energy which is stored in various organic products in the plants. When the herbivores consume plants as food and convert chemical energy accumulated in plant products into kinetic energy, degradation of energy will occur through its conversion into heat. When herbivores are consumed by carnivores of the first order (secondary consumers), further degradation will occur. Similarly, when primary carnivores are consumed by top carnivores, again energy will be degraded.

Trophic level. The producers and consumers in ecosystem can be arranged into several feeding groups, each known as *trophic level* (feeding level). In an ecosystem, producers represent the first trophic level, herbivores represent the second trophic level, primary carnivores represent the third trophic level and top carnivores represent the last level.

Food Chain

In the ecosystem, green plants alone are able to trap in solar energy and convert it into chemical energy. The chemical energy is locked up in the various organic compounds, such as carbohydrates, fats and proteins, present in the green plants. Since virtually all other living organisms depend upon green plants for their energy, the efficiency of plants on any given area in capturing solar energy sets the upper limit to long-term energy flow and biological activity in the community. The food manufactured by the green plants is utilized by themselves and also by herbivores. Animals feed repeatedly. Herbivores fall prey to some other carnivorous animals. In this way one form supports the other form of life. Thus, food from one trophic level reaches to the other trophic level and in this way a chain is established. This is known as *food chain*. A food chain may be defined as the transfer of energy and nutrients through a succession of organisms through repeated process of eating and being eaten. In food chain initial link is a green plant or producer which produces chemical energy available to consumers. For example, marsh grass is consumed by grass hopper, the grass hopper is consumed by a bird and that bird is consumed by hawk. Thus, a food chain is formed which can be written as follows :

Marsh grass → grass hopper → bird → hawk

Food chain in any ecosystem runs directly in which green plants are eaten by herbivores, herbivores are eaten by carnivores and carnivores are eaten by top carnivores. Man forms the terrestrial link of many food chains.

Food chains are of three types :

1. **Predator Chain**. Which starts from plant and goes from smaller to larger animals.

2. **Parasitic Chain**. It goes from large to smaller organisms.

3. **Saprophytic Chain**. It goes from dead matter to micro-organisms. It is also known as *detritus food chain*.

The energy contained in this detritus is not lost to the eco-systems as a whole, but it serves as the source of energy for a group of organisms which is called detritus food chain.

Food Web. Many food chains exist in an ecosystem, but as a matter of fact these food chains are not independent. In ecosystem, one organism does not depend wholly on another. The resources are shared specially at the beginning of the chain. The marsh plants are eaten by variety of insects, birds, mammals and fishes and some of the animals are eaten by several predators. Similarly, in the food chain, grass→mouse→snakes→owls, sometimes mice are not eaten by snakes but directly by owls. This type of interrelationship inter-links the individuals of the whole community. In this way, food chains become interlinked. A complex of interrelated food chains makes up a food web. Food web maintains the stability of the eco-system. The greater the number of alternative pathways the more stable is the community of living things. Fig. 3.3*d* illustrates a food web in ecosystem.

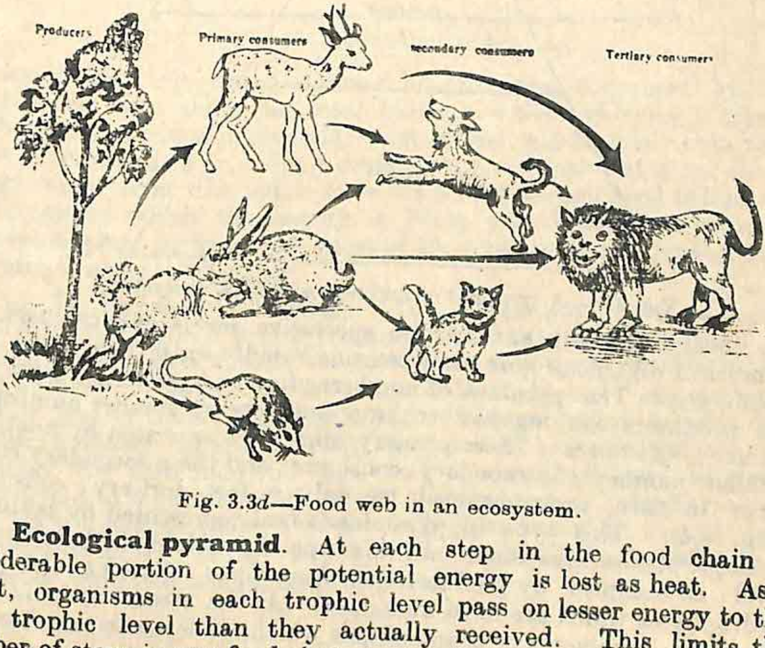


Fig. 3.3*d*—Food web in an ecosystem.

Ecological pyramid. At each step in the food chain a considerable portion of the potential energy is lost as heat. As a result, organisms in each trophic level pass on lesser energy to the next trophic level than they actually received. This limits the number of steps in any food chain to 4 or 5. Longer the food chain the lesser energy is available for final members. Because of this tapering off of available energy in the food chain a pyramid is formed that is known as ecological pyramid. The higher the step in the ecological pyramid the lower the number of individuals and the larger their size.

The use of ecological pyramids was advanced by C.E. Elton (1927). There are different types of ecological pyramids. In each ecological pyramid producer level forms the base and successive levels make up the apex. These types of pyramidal relations may be found among the organisms at different levels in the ecosystem. These are :

1. Pyramid of numbers.
2. Pyramid of biomass (biomass is the weight of living organisms).
3. Pyramid of energy.

1. **Pyramid of numbers**. It depicts the numbers of individuals in producers and in different orders of consumers in an ecosystem. The base of pyramid is represented by producers which are the most abundant and in the successive levels of consumers, the number of organisms goes on decreasing rapidly until there are a few carnivores. The pyramid of numbers of an ecosystem indicates that the producers are ingested in large numbers by smaller numbers of primary consumers. These primary consumers are eaten by relatively smaller number of secondary consumers and these secondary consumers, in turn, are consumed by only a few tertiary consumers (Fig. 3.4). This type of pyramids is best represented by taking an example of lake ecosystem. In this type of pyramid the base trophic level is occupied by producer elements—algae, diatoms and other hydrophytes which are most abundant. At the second trophic level come the herbivores or zooplanktons which are lesser in number than producers. The third trophic level is occupied by carnivores which are still smaller in number than the herbivores and the top is occu-

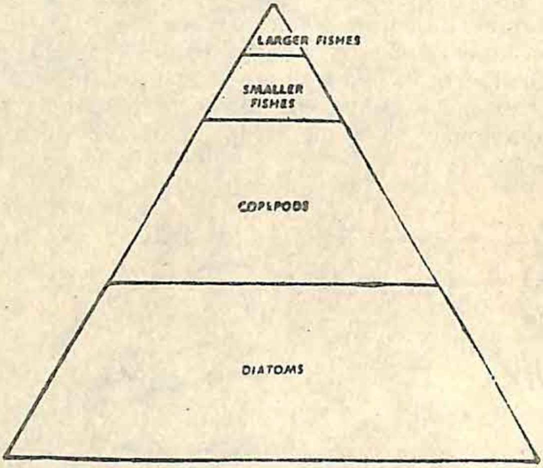


Fig. 3.4 —A pyramid of numbers of a lake ecosystem.

pied by a few top carnivores. Thus, in the ecological pyramid of numbers there is a relative reduction in number of organisms and an increase in the size of body from base to apex of the pyramid.

2. **Pyramid of biomass of organisms**. The living weight or *biomass* of the members of the food chain present at any one time forms the pyramid of biomass of organisms. This indicates, by weight or other means of measuring materials, the total bulk of organisms or fixed energy present at any one time. Pyramid of biomass indicates the decrease of biomass in each trophic level from base to apex, *e.g.*, total biomass of producers consumed by herbivores is more than the total biomass of the herbivores. Likewise, the total biomass of secondary consumers will be lesser than that of herbivores and so on. Since some energy and material is lost in each successive link, the total mass supported at each level is limited by the rate at which the energy is being stored below. This usually gives sloping pyramid for most of the communities in terrestrial and shallow water ecosystems.

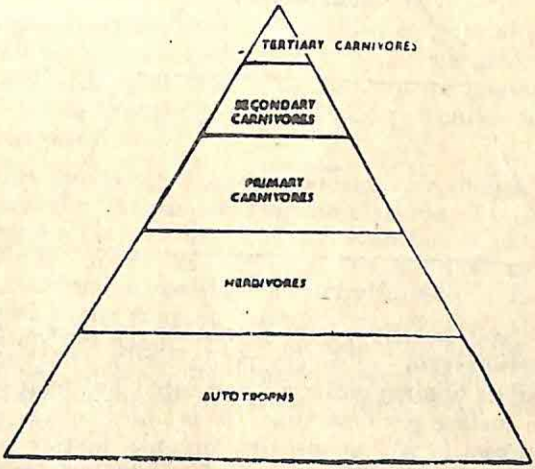


Fig. 3.5—A pyramid of biomass.

3. **Pyramid of energy**. This depicts not only the amount of total energy utilized by the organisms at each trophic level of food chain but more important, the actual role of various organisms assume in transfer of energy. At the producer level the total energy will be much greater than the energy at the successive higher trophic level. Some producer organisms may have small biomass but the total energy they assimilate and pass on to consumers may be greater than that of organisms with much larger biomass. Higher trophic levels are more efficient in energy utilization but much heat is lost in energy transfer. Energy lost by respiration also progressively increases from lower to higher trophic state.

Productivity

Green plants fix solar energy and accumulate it in the organic material in chemical form. The energy accumulated by producers is called *production* or more especially *primary production*. Since it is the first and basic form of energy storage, the rate at which the energy accumulates in the green plants or producers is known as **primary productivity**. Primary productivity is the rate at which energy is bound or organic material is created by photosynthesis per unit of earth's surface per unit time; it is most often expressed as energy in calories / cm^2 / yr or dry organic matter in g / m^2/ yr ($g/m^2 \times 8.92 = lb.$ / acre). The amount of organic matter present at a given time per unit area is called **standing crop** or **biomass** and as such productivity, which is a rate, is quite different from biomass or standing crop. The standing crop is usually expressed as dry wt. g/m^2 or kg/m^2 or as t/ha (metric tons), $10^6 g$/hectare. Primary productivity is the result of photosynthesis by green plants including algae of different colours. Bacterial photosynthesis or chemosynthesis, although of small significance may also contribute to primary productivity. The total solar energy trapped in the food material by photosynthesis is referred to as **gross primary production**.

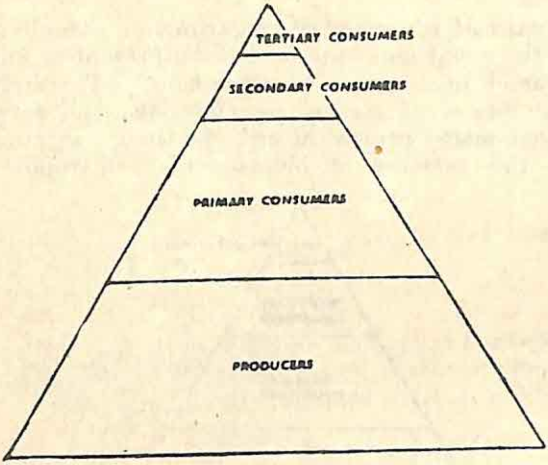


Fig. 3·6—A pyramid of energy.

A good fraction of gross primary production is utilized in respiration of green plants. The amount of energy-bound organic matter created per unit area and time that is left after respiration of these plants is **net primary production** or **Plant growth**. Only the net primary productivity is available for harvest by man and other animals. Net productivity of energy = gross productivity—energy used in respiration. The rates at which the heterotrophic organisms resynthesize the energy yielding substances is termed as *secondary productivities*. Secondary productivities are the productivities of animals and saprobes in communities.

There are three fundamental concepts of productivity :

1. Standing crop
2. Materials removed
3. Production rate.

1. **Standing crop**. It is the abundance of the organisms existing in the area at any one time. It may be expressed in terms of number of individuals, as biomass of organisms, as energy content or in some other suitable terms. Measurement of standing crop reveals the concentration of individuals in the various populations of the ecosystem.

2. **The materials removed**. The second concept of productivity is **the materials removed** from the area per unit time. It includes the yield to man, organisms removed from the ecosystem by migration, and the material withdrawn as organic deposit.

3. **The production rate**. The third concept of productivity is the **production rate**. It is the rate at which the growth processes are going forward within the area. The amount of material formed by each link in the food chain per unit of time per unit area or volume is the production rate.

All the three major groups of organisms—producers, consumers and reducers are the functional kingdoms of natural communities. The three represent major directions of evolution and are characterised by different modes of nutrition. Plants feed primarily by photosynthesis, animals feed primarily by ingesting food that is digested in and absorbed from an internal cavity and the saprobes feed by absorption and have need for an extensive surface of absorption. The principal kinds of organization evolved among saprobes are the unicellular bacteria, yeasts, chytrids of lower fungi and a higher fungi with mycelial bodies.

In terrestrial communities as much as 90% of net primary production remains unharvested and must be utilized as dead tissue by saprobes and soil animals. In terrestrial ecosystems, the saprobes have a larger and more essential role than animals in degrading dead organic matter to inorganic forms and in such ecosystems, secondary production by reducers (decomposers) should exceed that by consumers, though the former is even more difficult to measure than the latter. Biomass of decomposers with their microscopic cells and filaments embedded in good sources, is also difficult to measure and that is small in relation to their productivity and significance for the ecosystem. Small masses of reducers degrade and transform for larger masses of organic matter to inorganic remnants. In so doing decomposers disperse back to the environment the energy of photosynthesis accumulated in the organic compounds that decompose. Thus, they have a major part in the energy flow of ecosystems. A community or ecosystem, like an organism, is an open energy system. The continuous intake of energy by photosynthesis replaces the energy dissipated to environment by respiration and biological activity and the system does not run-down, through the loss of free energy to maximum entropy. If the amount of energy entrapped is greater than the energy dissipated, the pool of biologically useful energy of organic bonds increases. This results in increase of community biomass and consequently the community grows; such is the case in succession. If energy intake is less than energy dissipation, the community biomass will decrease and it must, in some sense, retrogress. If energy intake and loss are in balance, the pool of organic energy is in steady state; such is the case in climax communities. Three aspects of this steady state may be recognised : (*i*) The steady state of populations of climax communities in which equal birth and death rates in population keep the number of individuals relatively constant, (*ii*) The steady state of energy flow, (*iii*) The steady state of the matter of community, where addition of material by photosynthesis and organic synthesis is balanced by loss of material respiration and decomposition.

BIOGEOCHEMICAL CYCLES

Nearly 30 to 40 elements are required for the proper growth and development of living organisms. Most important of these are C, H, O, P, K, N, S, Ca, Fe, Mg, B, Zn, Cl, Mo, Co, I and F. These materials flow from abiotic to biotic components and back to the non-living component again in a more or less cyclic manner. This is known as the biogeochemical cycle or inorganic-organic cycle. The flow of these elements through the ecosystem must be cyclic, with matter being consistently reused. Because the flow involves not only living organisms, but also a series of chemical reactions in the abiotic environments, these cycles are called biogeochemical cycles.

There are three type of biogeochemical cycles :

(1) Hydrologic cycle or water cycle,
(2) Gaseous cycle,
(3) Sedimentary cycle.

1. Hydrologic or water cycle. Interchange of water between atmosphere, land and sea and between living organisms and their environment is accomplished through water cycle. Water cycle or hydrologic cycle involves evaporation, transpiration, cloud formation, precipitation, surface water run off and percolation. Of these, the key process is evaporation since it maintains the humidity of the atmosphere and feeds back the moisture necessary for cloud

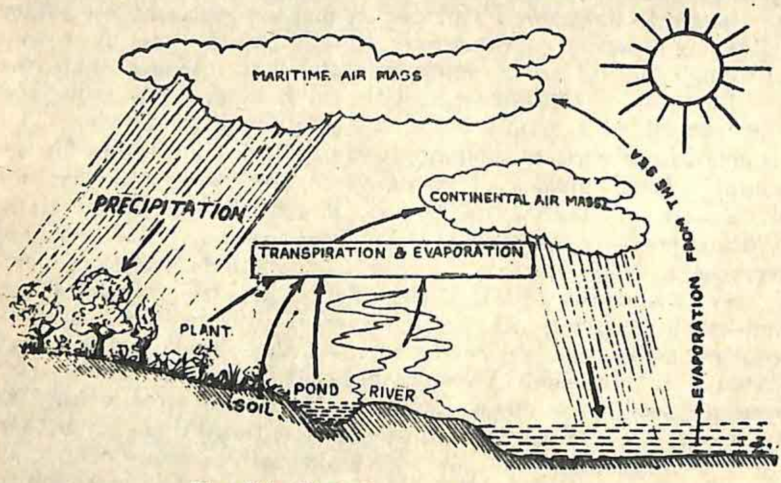


Fig. 3.7—Hydrologic cycle in nature.

formation and precipitation. Water of atmosphere reaches to the earth surface through precipitation and from the earth surface it reaches to the atmosphere through evaporation and transpiration. The amount of water available for evaporation is determined by the amount supplied by precipitation and condensation. Between rainfall input and evaporation output there lies a precarious water balance (Fig. 3.7).

2. Gaseous Cycle

Oxygen cycle. Oxygen is found in free state in atmosphere and in dissolved state in water. It is liberated as byproduct of photosynthesis and is utilized in respiration by all the plants and animals. When the living organisms respire, CO_2 is liberated which is utilized by green plants as an essential raw material for carbohydrates synthesis. In this way a simple yet vital O_2 cycle is maintained in the ecosystem.

Carbon cycle. Carbon is the basic constituent of all organic compounds. Since energy transfer occurs in the consumption and storage of carbohydrate and fats, carbon moves to the ecosystem with flow of energy. The source of nearly all carbon found in the living organisms is CO_2 which is found in free state in atmosphere and in dissolved state in the water on the earth. Green plants (producers) use CO_2 through photosynthesis in the presence of sunlight and carbohydrate is formed. Later on complex fats and polysaccharides are formed in plants which are utilized by animals. Flesh eating animals (carnivores) feed on herbivores and the carbon compounds are again digested and converted into the other forms. Carbon is released to the atmosphere directly as CO_2 in respiration of both plants and animals. Bacteria and fungi attack the dead remains of plants and animals. They degrade the complex organic compounds into simple substances, which are then available for other cycles. Part of the organic carbon becomes incorporated into the earth's crust as coal, gas, petroleum, limestone and coral reef. Carbon from such deposits may be liberated after a long period of time (Fig. 3.8).

Nitrogen cycle. Of all the elements which plants absorb from the soil, nitrogen is most important for plant growth. This is required in greatest quantity. Green plants obtain nitrogen from the soil solution in the form of ammonium or nitrates or nitrite ions. The most important source of nitrogen for green plants is nitrogen that is fixed by nitrogen fixing bacteria. Some of the nitrogen fixing bacteria inhabit the root nodules of leguminous and some other plants and some others are found free in the soil. Nitrogen is directly taken from the air by nitrogen fixing root nodule bacteria (rhizobia) or by free living aerobic bacteria (*Azotobacter*) or by anaerobic soil bacteria (*Clostridium*). These bacteria make nitrogen available to the plants and add to their growth. Some blue green algae, as for example, species of *Nostoc* and *Anabaena* also perform nitrogen fixation. When nitrogen is absorbed as nitrate it has to be reduced to ammonia before being used in amino acid and protein synthesis. The breakdown of dead tissues by decay bacteria releases ammonia from protein and other nitrogenous compounds. Nitrosomonas bacteria

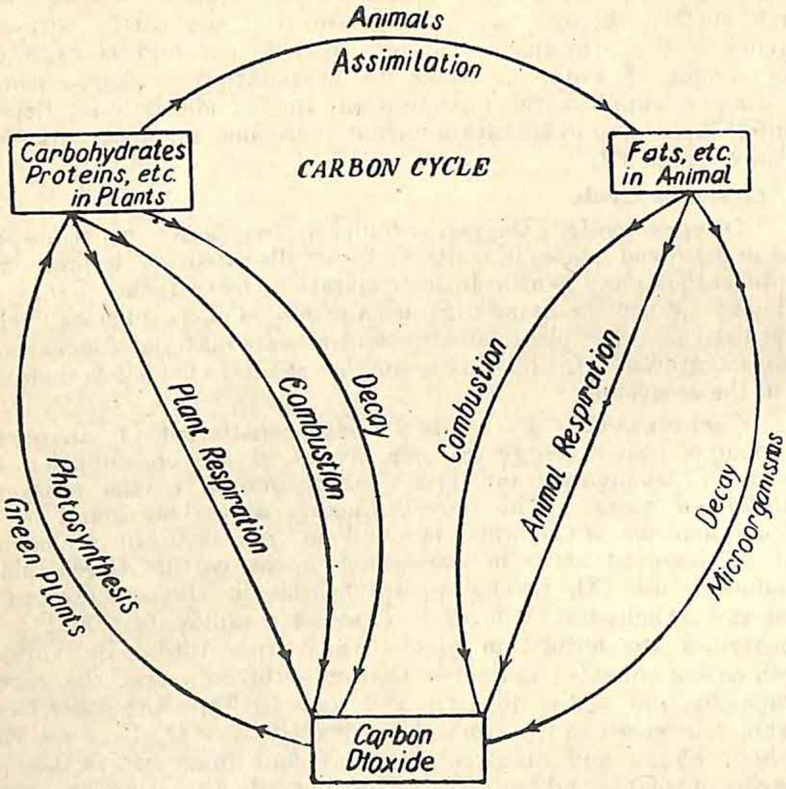


Fig. 3.8—Carbon cycle in ecosystem

oxidize ammonia into nitrites and still other bacteria (Nitrobacter) oxidize nitrite to nitrate (Nitrification). Ammonia is also directly converted into free nitrogen by denitrifying bacteria (Denitrification), In this way, the nitrogen cycle is repeated in the ecosystem.

The overall nitrogen cycle in nature is represented in Fig. 3.9.

3. Sedimentary Cycle

Mineral elements required by living organisms are obtained initially from inorganic sources. Available forms occur as salts dissolved in soil water. Mineral cycle essentially consists of two phases : (*i*) The salt solution phase and (*ii*) rock solution phase.

Mineral salts come directly from earth crust by weathering. Soluble salts then enter the water cycle. By movement of water minerals move from the soil to streams, lakes and ultimately to sea where they remain permanently. Other salts return to the earth's crust through sedimentation. They become incorporated into sediments or beds and after weathering of rocks they again enter the cycle. Plants and some animals take minerals in the form of mineral solution from their habitats. After the death of living organisms the minerals return to the soil and water through the action of decomposers (bacteria and fungi) and transformers. Green plants at one end and decomposers at another play very important role in circulation of nutrients.

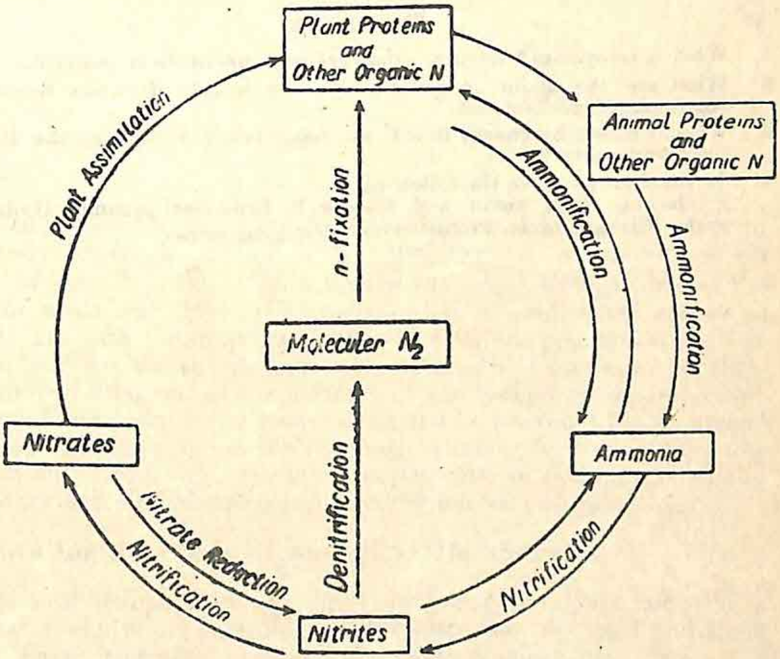


Fig. 3.9.—The nitrogen cycle in ecosystem

Phosphorus cycle. Plants and animals obtain phosphorus from the environment and when they die the decomposers attack them and liberate phosphorus to the environment. This process proceeds in cyclic way. Phosphorus, calcium and many other elements also reach the oceans in dissolved state and there they undergo sedimentation (accumulation). In the sedimentary deposits the nutrients are locked up for indefinite period and in this way, they are separated from the cyclic pathway. When sediments weather, the nutrients become free for another cycle.

Other Nutrient Cycles

The nutrient cycle is not a close circuit within an ecosystem. The nutrients are continuously being imported as well as being carried out of the ecosystem. Appreciable quantities of plant nutrients are brought to ecosystem by rain and snow. Small quantity of nutrients carried to the forest is by rains. The gain of nutrients to the ecosystem from precipitation, extraneous material and mineral weathering is offset by losses. Water draining away from forest carries with it more mineral matter than supplied through precipitation. Considerable quantities of nutrients in the forest are locked up in the trees and the humus layer. When trees and vegetation are removed, sufficient amount of nutrient are removed.

Intensive forestry and agriculture on some soils may reduce the nutrient reserves to such an extent that soils become unfertile. Ecosystem can remain productive only if the nutrients withdrawn are balanced by an inflow or replacement.

Questions

1. What is ecosystem ? What are the various components of ecosystem ?
2. What are the major ecosystems of the world ? Describe forest and pond ecosystems in detail.
3. What is meant by energy flow in an ecosystem ? What are the laws of thermodynamics ?
4. Write short notes on the following :
   Producers, Food chain and Food web, Ecological pyramid, Hydrologic cycle, Nitrogen cycle, Productivity. Ecological niches.

4

AUTECOLOGY

Autecology is the branch of ecology which is concerned with the study of single species in a population or community at all stages of its life cycle. This special branch of ecology aims at the study of ecological life cycle, distribution of individual species in natural habitats, adaptations, differentiation of population etc. It shall help to explain the structure and dynamics of communities, since only from working out of complexities of the ecology of the important species of communities, a sound basis can be provided for an understanding of vegetation problem. Much stimulus for such studies has come mainly from the economic importance of certain species and agriculture and silviculture one, indeed, extensions of autecology.

Outlines for the study of ecological life histories

Several eminent workers have prepared detailed scheme for a systematic study of autecological life histories. Stevens and Rock (1952) have suggested scheme for autecological life histories of herbaceous plants. Pelton (1951) has given a scheme for the study of autecological life histories of trees, shrubs and stem succulents ; Curtis (1952) for vascular epiphytes; and Cooke (1951) for fungi and they have emphasized for the study of environment and performance of plants. The main purpose of such studies should be to uncover the response of various forms of life to stimuli and compulsions of environment and also to throw light on the limits of its geographical distribution and causes related to this. The different aspects in the study of autecology of an individual species are outlined below :

(1) In any ecological or botanical study identification of plants is the first requisite. Taxonomy and nomenclature of the species under study are discussed. Under nomenclature scientific valid names, various synonyms and common names are discussed. The confirmation of correct identification is advisable in a standard regional or central herbarium. The botanical survey of India has developed a chain of herbaria; Central National Herbarium at Sibpur, Howrah, Regional Herbaria at Poona, Coimbatore, Shillong, Dehradun and Allahabad. Besides, a small Economic plant herbarium exists at Central Botanical Laboratory, Calcutta. These herbaria maintain large collections of correctly identified and properly arranged plants specimens and run a plant identification service.

Associates. The species associated with the plant species under study should be recorded in a number of habitat conditions in order to get a proper range of variations. Associate species indicate the sociability and adaptations of a plant.

(2) **Distribution and Importance**. The range of distribution, altitudinal and latitudinal limits and its ecological importance in various regions and habitats are noted. The degree of dominance or subdominance of species in different types of vegetation; its place in succession; whether pioneer or seral member or a component of climax community; its economic importance for browse, timber, pulp, fruits, in erosion and medicine are emphasized.

(3) **Morphology of plants.** In this, the distinguishing features of various plant parts are described. Structural variations are also noted in the plants of same species growing on the different ecological habitats.

(4) **Cytogenetics of plant species.** Cytological features, such as the structure of cytoplasm, chromosomes morphology, and the number and behaviour of chromosomes during mitosis and meiosis are studied in detail. Sometimes plants of the same species growing geographically isolated become so much differentiated and morphologically changed that they are often supposed as different species. In such cases, interbreeding experiments are made. If the individuals interbreed, it is supposed that they belong to the same species. Variations in nature and factors for segregation are discussed.

(5) **Physiology of the plant.** Various physiological processes of the plants of the particular species are studied in detail and the factors influencing the rates of those processes are also taken into consideration.

(6) **Environment complex.** Both biotic and abiotic aspects are measured quantitatively at different stages of plant growth at regular intervals in order to study the phenology (germination, leaffall, initiation of flower bud, etc.) in relation to different seasons of the year. The environmental complex which is made up of several factors in various combinations affects each stage of plant's life cycle. In the foregoing discussion correlations of phenology to the various environmental changes are discussed :

(1) **Flowering.** Various environmental factors, such as, light, temperature of the soil and atmosphere, percentage of nutrients in the soil etc. affect the flowering process of plants. In autecology of a species, the period of flowering as well as the specific role of different environmental factors on flower initiation is noted. The photoperiodic effects and temperature effects on the flowering are studied in detail.

(2) **Pollination**. During pollination, the environmental factors help the plant to a great extent. Some plants may be pollinated by wind, some by water and some others by biotic agencies such as insects, birds and even man.

(3) **Fruiting.** The structure and number of fruits, number of seeds per fruit, season of fruiting, etc. are some of the important aspects in study of ecological life cycle of a species. The environmental factors by way of their influence on the fruiting of the plants determine the success or failure of particular species of the community in regeneration and establishment. Biotic factors, especially certain disease causing fungi and insects, damage fruits and thus affect fruit formation to a great deal.

(4) **Seed output.** The number of seeds proudced by a plant in one reproductive flux is known as *seed output*. The seed output is measured by the following methods :

Average number of seeds per fruit $= a$
Average number of fruits per plant $= b$
Average seed output $= (a \times b)$
Average number of fruits per branch (for trees and shrubs) $= b_1$
Average number of branches per plant $= b_2$
Average number of fruits per plant $= (b_1 \times b_2)$
$\therefore$ Average seed output for trees $= a(b_1 \times b_2)$

Counts for seed output are made from the plants growing in a number of diverse localities in order to get a correct assessment. In autecology the knowledge of seed output is of a great importance. It is commonly observed that annuals reproduce only once in their life, whereas the perennial shrubs and trees produce seeds usually once in a year but many times in their life time. Every species has its own range of seed output. The range of seed output may be affected by many habitat factors, both biotic and abiotic. So while taking into consideration the seed output of particular species, various factors which affect it are also considered.

(5) **Dispersal of seeds.** Shape, size, weight and volume of seeds are important characters which govern the mode and extent of dispersal. Distribution and success in the establishment of plant species on the habitats are governed directly by the distribution of their seeds. If the seeds scattered round the mother plants and allowed to grow, the new plants developing from them will have little chance for survival and regeneration because of over-crowding. Movement of plant populations to wider areas ensures success in the establishment of species. Thus the study of dispersal of seeds of plants is one of the important aspects of autecology. The dispersal mechanisms and the agencies causing the dispersal of seeds and other reproductive bodies are also studied in autecology.

(6) **Viability of seeds.** Seeds have life spans of their own. They lose their power of germination after some time if stored under favourable conditions for long period. The period right from their formation up to the time when they begin to lose their germination capacity is called 'viability period'. This period varies from species to species. In some cases, the viability period is zero and the seeds are totally incapable to germinate.

To test the viability, seeds are placed in Petri-dishes or sawdust every week from the day of maturation and seedfall. The experiment is continued till the seeds do not germinate at all.

For calculating the percentage of viable seeds in a given seed sample, seeds are cut and dipped in dilute solution of TTC (Tetra zolium trichloride) with a little sucrose. After 24 hours. if the embryos of dipped seeds become pink, such seeds are treated as viable.

The seeds of many crop plants remain viable for 5 to 10 years. In *Mimosa glomerata*, *Cassia bicapsularis* and *Astragalus massibiensis* the seeds are reported to be viable even after over one hunderd years of storage. It is usually long in the seeds that can not germinate immediately after formation. Viability is affected by the conditions prevailing in the particular place where the seed is stored. It has been observed that the conditions which reduce has metabolic activities are usually responsible for increasing the seeds longevity. Low temperature, low oxygen and high CO_2 contents in the atmosphere have marked effects in increasing the viability period of seeds.

(7) **Dormancy.** In some cases the viable seeds do not germinate up to a certain length of time even if the conditions for germination are favourable. This period is called dormancy period and such seeds are said to be in dormant stage and this phenomenon is known as dormancy. Dormancy may be on account of physiological immunity for germination or due to impermeability of seed coat to water and gases or due to specific light requirements or due to the presence of some germination inhibiting substances. Recently caumarin and its derivatives have been found to be present in the dormant seeds of some species. The dormancy can be broken by the following methods :

(*a*) **Mechanical methods.** When the dormancy is caused by hard seed coats that are impermeable either to water or to oxygen or both, it can be broken by abrasion, removal or puncture of seed coat. *Coriander* seeds are pounded mechanically before sowing, which gives high percentage of germination.

(*b*) **Temperature.** The following alternating temperatures are usually given to seeds for breaking dormancy : (*i*) 0°C and 10°C, (*ii*) 30°C and 45C°, and (*iii*) 0°C and 45°C. Higher temperature may also break dormancy *e.g.*, in *Cassia occidentalis*.

(*c*) **Irradiation of seeds.** Irradiation of seeds to red light breaks the dormancy and increases the germination percentage in some plants. X-rays and Gamma-rays have also been found to break dormancy.

(*d*) **Chemical treatments.** Many chemicals are known to affect germination of seeds. Dormancy of seeds can be broken by dipping them in conc. H_2SO_4 for a few minutes (say 2 to 5 minutes) following by thorough washing in water. Sometimes it can be broken by putting soaked seeds in solution of copper sulphate, or potassium permanganate or hormones.

(*e*) **Removal of inhibitors of Germination.** When the dormancy is caused by the presence of some germination inhibiting substances, it can be removed by washing the seeds in running water for varying periods of time before placing them for germination.

(8) **Food germination and reproductive capacity.** All the seeds may or may not germinate ; some of them are unviable. Some do not get proper conditions for germination and some may be destroyed by living organisms and by excess water. According to Salisbury (1942), the percentage of germinated seeds in the average seed output is called 'reproductive capacity'.

$$\text{Reproductive capacity} = \frac{\text{Average seed output of a plant} \times \text{Percentage of germinated seeds}}{100}$$

The reproductive capacity and the seedling establisment are significant for physiognomy (outward appearance) and sociological structures of species population. The process of seed germination is controlled by several factors, such as, temperature, dormancy of seeds, availability of water, concentrations of oxygen and carbon dioxide, pH value of medium and so on. In autecology of a plant species the different factors which influence the seed germination are also taken into account.

(9) **Seedling and vegetative growth.** When mature and viable seeds get favourable conditions for germination, they start germinating and after some time they establish their seedlings. Proper development and growth of seedlings are important factors for the survival of the plant. Growth performance of shoot and root in relation to climate, physiography, soil character (physical and chemical both), fire, root/shoot ratio, stomatal counts, their physiology of movements are considered. Besides, the aerial and underground productivity in various habitats and communities, water requirement (the amount of water required per gm. of dry weight) are also studied. Several factors influence the growth and establishment of seedlings. Many seedlings of sal develop on moist leaf litter during rainy season but the onset of dry season even for a short period due to interruption of rains may kill many of them and unless the roots of seedlings have penetrated deep enough in the soil establishment of seedlings cannot be achieved. The aerial shoots of seedling of sal "*die back*" year after year but the root growth continues. Shoots regenerate every year during or before the rains. This phenomenon of "die back" continues for 20 to 25 years and only after the roots have become established in deep strata of soil with good supply of water and nutrients does the plant shoot up and establishes itself. In autecological studies, thus, the knowledge about seedling growth, establishment of young seedling in a particular area and climate is essential. The intensity of solar radiations, durations and quality of light, temperature, soil conditions, water, etc. affect vegetative growth of any species. Every species in a population or community has its own requirements for the environmental conditions and has its own ecological amplitudes of tolerance to an extent of fluctuation towards higher and lower sides from the optimum. Interspecific and intraspecific competitions for space, nutrients, light, water, etc. may also

wipe out or delay the establishment of seedlings. Dense shade of trees and absence of sufficient light may have lethal effects for seedlings of some species. Interspecific and intraspecific competitions may be studied by growing varying number of seedlings of the same species (intraspecific) and those of associated species (interspecific) in mixed condition in a unit area and recording growth performance (mainly dry weight) of individual plants under all conditions. Important roles of the various environmental factors in the life of plants have been given in the chapter 2.

In brief, autecology concerns with the study of individual organisim or an individual species. In this branch of ecology, the life history and behaviour as a means of adaptation to the environment are usually emphasized. Autecology is directly related with synecology and it is regarded as the foundation upon which synecology is built. In the study of synecology the knowledge of life history (autecology) of prominent members of community is very essential.

Questions

1. What is autecology ? How it is studied ?
2. Write short notes on :
   - (*i*) Seed output
   - (*ii*) Seed viability
   - (*iii*) Reproduclive capacity.
   - (*iv*) Dormancy

5

SYNECOLOGY OR STUDY OF COMMUNITIES

No plant or animal lives as isolated individual. Plants and animals generally prefer to live in groups or colonies. Different plants and animals living in a habitat constitute a biotic community. When only assemblage of plants in a habitat is considered, it is called *plant community*. Similarly, assemblage of animals in a habitat is called *animal community*. In any biological organization plants and animals are very closely related and interdependent and at a particular place plants and animals share the same set of conditions and same environment. In view of these facts, modern biologists prefer use of biotic community to plant community or animal community. The study of the relationships of plants and animals making up a natural community is termed as *community ecology* or *synecology*.

The basic unit of vegetation is called plant community or a plant association. The communities are not the random mixtures of species. The species living together in groups exhibit various degrees of adjustment among themselves and with their physical habitats as well. Each community consists of a set of many different species which persist year after year. In a community, each plant species is represented by innumerable individuals. A group of individuals of the same species is commonly known as *population*. Thus a population is a part of community and populations of different species may be intermingled in a community. Oosting defines community as "an aggregation of living organisms having mutual relationship among themselves and to the environment". In modern books of ecology, plant community is defined as *'uniform floristic composition'*. Earlier Gleason (1939) in his individualistic concept of plant association suggested that an association is a complex of slight irregularities, all of which blend into an entirety of apparent homogeneity. It is uniform either in space or in time and possesses definite limits of area only to a reasonable extent.

Pondeyar (1960, 1961) has discussed this subject and suggested that an association is a temporary phenomenon which is continuous in space and with slight irregularities, all of which blend into an entirety of apparent abstract homogeneity. According to him the association is not a final vegetation but an assemblage of plants of any status. Misra and Puri (1954) and Puri (1960) are of the opinion that Elements' original concept, which defined "community as any unit of vegetation, whether developmental or climax in status", should be accepted as such and they used the term **association** for *climatic climax*. According to them, the climatic climax community is in complete equilibrium not only with climate but also with the whole complex of environment.

Community Composition

The following points characterised the community:

(1) **Species diversity.** The biotic community is a natural assemblage of a large number of plant and animal species in an area. Actually it is a part of a larger whole ecosystem in which living and non-living component interacte and bring about circulation, transformation and accumulation of energy and matter.

Because in any particular habitat there is no considerable variation in environmental conditions, the plants growing together in a community show unique uniformity in their behaviour. Vegetation, therefore, is reflection of a climate and, in general, widely separated areas having similar climate have similar aspects of landscape.

Some community areas have limits but more often the community boundaries are hard to define. A clearly distinguished area or a type of area with uniform habitat conditions and supporting characteristic type of vegetation is termed "biotope".

Each species of communitv has got definite range of tolerance towards the physical and biological environmental conditions of the habitat. The range of environment a species can tolerate is called its **ecological amplitude**. The nature of community of a particular habitat is determined by the species contents, ecological amplitudes of the species and physical and biotic influences prevailing in the locale of community.

(2) **Coexistence.** Species occurring in their particular habitat do not live in complete isolation as pure cultures, but they coexist in mutual adjustment. The coexisting populations are inter-related and they show some sorts of interaction. The relationships, between coexisting species may be obligatory in one direction or in both. The trees in a forest community can live just as good as without shrubs and herbs which grow under them. This relationship is obligatory in one direction only. The relationship between plants and animals which pollinate them is obligatory in both directions.

The nature of interaction between two coexisting species may fall into one of the following types :

(i) **Exploitation**. In this, one species lives at the expense of another.

(ii) **Mutualism**. In this, one species or both coexisting populations benefit from the relationship but none suffers.

(iii) **Competition**. In this two populations may compete for some resources of the habitat.

(iv) **Neutralism**. In this two populations may be quite independent and neither population affects the other.

(3) **Interdependency**. All the members of a community have ability to live under the conditions of the habitat and they are interdependent upon one another to some extent. It is called *dependency*. Thallophytes, mosses, ferns and many shade loving

herbs that are found on the forest floor are dependent on the forest trees because trees provide shadow and moist conditions. If the trees of forest are removed, the ground vegetation may disappear. Similarly the fungi and saprophytes found in the forest depend upon the roots of plants and on the rich humus and some fungi form mycorrhizal associations with the plant roots. Some sort of relationship exists between plants and the insects and other animals which pollinate them.

(4) **Species Dominance**. Not all the species of a community are found in abundance. Only a few species are found in abundance, either in number or in biomass (living weight) while the majority are rare. The common species which are more abundant and contain more biomass are considered to be dominants. Dominant individuals influence the associated individuals. In the forest, tallest trees, for example, influence the under-storey plants and ground vegetation not only by decreasing the intensity of light reaching to the forest floor and increasing the moisture content of air but also by changing the soil structure and its chemical composition. The dominance in the community may be the result of co-action between two or more species. Different communities are generally recognised and named on the basis of dominant species occurring in them.

(5) **Stratification**. In a plant community, the plants, which have some sort of relationship among themselves, may be trees, shrubs, herbs, mosses, lichens and thallophytes. These plants form more or less distinct strata or layers or storeys on vertical as well as in horizontal planes. This is characteristically known as *stratification.* The individuals of different layers represent different *"life forms"*. Each layer of community may sometimes include individuals of different morphological classes, as for examaple, the top layer or canopy of forest may be formed by tallest trees and lianes (woody climbers). In order to overcome this objection, plants belonging to different morphological classes are put in 'sinusiae' (singular—sinusia), as for example, trees are put in sinusia of trees, epiphytes are put in sinusia of epiphytes, and so on.

In grassland, there are essentially three strata : (1) the root and rhizome layer, (2) the ground layer, and (3) herbaceous layer.

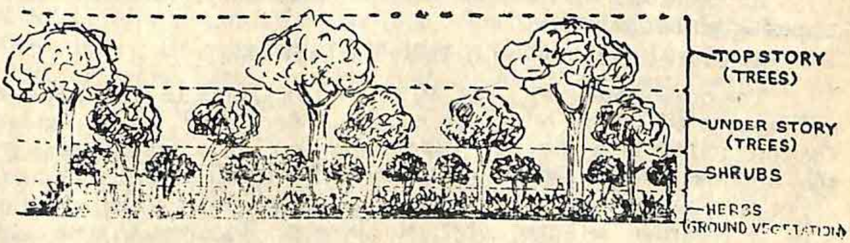


Fig. 5.1—A forest showing stratification of the plants.

In forest vegetation, the stratification reaches to its greatest complexity. Five vertical subdivisions (units of homogeneous life forms and ecological relations) may be present—(1) *subterranean zone*, (2) *forest floor*, (3) *ground vegetation* nearly extending upto a metre or so, (4) *understorey tree* and *shrub layer* extending to the height of one to five metres and (5) *tree layer* or *top storey* extending to the extent of 5 to 15 metres in most of the forests, but sometimes it may extend upto 25-30 m in the coniferous forests and to about 40 or 50 m in rain forest. In *sequoia* forest the upper canopy may surpass 100 m.

(6) **Succession.** Interacting populations of community are characterized by continuous death and replacement and usually by immigration and emigration (one way movement from home range to other habitat) of their individuals. In this way, composition and shape of community remains in changing state. The changes in the community go on taking place until a complete balance is established between community and environment. This is called succession. At complete equilibrium state a stable commnnity is established which is called *climax community*. In the climax community very little or no change in the shape can be anticipated over a long period of time.

A mixture of species which live in a habitat and are held together by common ecological tolerances form a community. As indicated earlier, some communities have sharply defined limits and they are characterized by a more or less, definite species contents, as for example, community of a pond or a small island or old field and burns. Thus they show *discontinuous* vegetational pattern.

There are, however, several instances of community types which do not have well defined limits and one community generally merges with another community. The species occurring in a community are not bound together into group of associates; they respond independently to the physical and biotic factors of the environment. Thus with the change in the environment, the composition, the community also tends to change. The sequence of communities showing a gradual change in composition is called *continuum* (Curtis 1959). Community in such a gradient can be recognized as a discrete point with uniform floristic composition in the *continuum*.

As regards the composition of community, there are two opposing philosophies :

(i) Organismic view, (ii) Individualistic view.

The organismic view was advanced by Clements (1916) and is still supported by his school of ecology. According to this view, the community is a sort of "*super organism*", the highest stage in the organisation of living world rising from cell to tissue, organs, organ-systems, species, population and to community. The community is regarded as super organism because it grows, adjusts, and under some circumstances reproduces itself and functionally it represents higher level of integration than individual plants and animals that make it up. The community acts as unit in the succession, in seasonal activity and in competition with other communities.

The individualistic concept was first advanced by H.A. Gleason (1926) and further extended by Whittaker (1951, 1952, 1956), Curtis (1958), McIntosh (1959) and several other ecologists. This approach emphasizes that no community necessarily reaches any prescribed composition or steady state. In this, species has been recognized as essential unit because it is only the species, and not the community, which is directly involved in inter-relationships and distribution. The species directly respond to the environmental conditions independently. They are not bound together in associates. The plants and animals exhibit a gradient or *continuum* from one extreme of environmental conditions to the other. In this approach of community composition the community is regarded as a continuous variable.

Ecotone. The transition or marginal zone between two major communities presenting a situation of special ecological interest is called an *ecotone* or *tension zone*. The transition zone between grassland and forest or the intermediate zone between any two major land or aquatic communities are the examples of ecotone. Strictly speaking, a transition zone is an ecotone only if tension exists between the bordering communities. The ecotone is colonized by the species that are commonly found in the communities on both the sides, as well as by some versatile species of plants and animals. As a rule, the ecotone contains more species and often denser populations than the bordering communities. This is known as *'principle of edges'*. This edge effect is chiefly due to wider range of suitable environmental conditions.

PHYSIOGNOMY

Life-form classes and Biological spectrum

The climate determines the type of plants that can exist in each region. General appearance of vegetation is referred to as **physiognomy**. It constitutes general stature, speed and life-forms of the species comprising the vegetation and actually the classification of vegetation types has been done on the basis of physiognomy. The species of a community can be grouped into several life-forms on the basis of general appearance and growth. The life-forms of the vegetation are to a certain extent indicators of the climate. This idea has been extensively developed by the Danish botanist Raunkiaer (1934). He considered that it is the unfavourable environmental condition which exerts a major control over the growth form and he stressed the significance of the adaptations of buds and shoot tips for overcoming adverse temperatures and surviving in drought. A classification of plants on the basis of the type and kind of perennating organs seems to be natural. Raunkiaer called the kind and type of these organs as **life-forms**. Raunkiaer employed three guiding roles in the selection of life-form characteristics :

(1) The character must be structural and essential and must represent important morphological adaptation.

(2) The character must be sufficiently clear that one can easily see in nature.

(3) All the life-forms employed must be of such nature that they constitute a homologous system and represent a single point of view or aspect of plants, and thus enable a comparative statistical treatment of flora of different communities. On the basis of these principles, he recognised five life-form groups. These groups are as follows :

(1) Phanerophytes
(2) Chamaephytes
(3) Hemicryptophytes
(4) Cryptophytes
(5) Therophytes

Cryptogams are not included in this system :

(1) **Phanerophytes.** In these, the perennating buds are located on the twigs and branches and are exposed to the atmosphere during unfavourable periods. Plants are mostly woody (trees and shrubs), although lianas, epiphytes and some large perennial herbs can be described under this group.

According to their heights, phanerophytes are divided into the following classes :

(*i*) Megaphanerophytes ; Perennial parts including buds are more than 30 metres in height.
(*ii*) Mesophanerophytes ; Between 8 and 30 metres height.
(*iii*) Microphanerophytes ; Between 2 and 8 metres height.
(*iv*) Nanophanerophytes ; Under 2 metres and over 25 cms tall.

The above height classes are further divided according to the conditions whether the meristematic tissues of buds are protected by bud scales or they are naked and whether the plants are evergreen or deciduous.

(2) **Chamaephytes.** Buds or shoot apices are situated on shoots that lie on or near the ground surface. Plants of this class are less than 25 cm in height, but their perennating buds are found definitely above the soil surface. During the unfavourable seasons, the buds are protected by the dead fallen leaves and on higher altitudes they are protected by snow. Chamaephytes are divided into the following classes :

(i) **Subfructicose chamaephytes.** Buds are protected by dead plant remains. Examples—Caryophyllaceae, Labiatae, Leguminosae, etc.
(ii) **Passive chamaephytes.** Shoots lie on the ground surface. Examples—*Saxifraga*, *Polygonum*, *Sedum*, etc.
(iii) **Active chamaephytes.** Buds lie on the ground and are protected by snow under the unfavourable conditions. Example—*Vinca*.
(iv) **Cushion chamaephytes.** They represent transition stage from chamaephytes to hemicryptophytes. In this group the shoots are closely packed, for example, *Azorella*.

(3) **Hemicryptophytes.** They are found on the soil surface and buds and shoots are protected by soil and dead leaves. They are herbaceous and spread on the surface horizontally as runners. The group is divided into protohemicryptophytes, partial rosette plants, and rosette plants.

(4) **Cryptophytes.** In this group, the buds and shoots of plants are underground. Reserve food material is stored in the subterranean perennating organs. The class is divided into the following categories :

(*i*) Geophytes
(*ii*) Helophytes
(*iii*) Hydrophytes

(**i**) **Geophytes.** They are land plants with subterranean perennating buds. They are of following types :

(I) Rhizome geophytes
(II) Stem tuber geophytes
(III) Bulb geophytes
(IV) Root tuber geophytes
(V) Root geophytes

(**ii**) **Helophytes.** These are the plants of water saturated soil. The leaves and flowers emerge above the ground but the rhizomes are subterranean.

(**iii**) **Hydrophytes.** They are water plants, for example—*Eichhornia*, *Nelumbium*, etc.

(5) **Therophytes.** This group includes such annual summer plants which survive under unfavourable seasons in the form of seeds. In summer, all the parts of plants die except seeds and fruits. Thus, the perennating bud is actually the embryo of the seed.

Braun Blanquet's Classification

Braun Blanquet (1951) modified classification of Raunkiaer and proposed a new scheme of classification of vegetation. The scheme is as follows :

1. **Phytoplankton** (microscopic floating plants)
   (*a*) Aeroplankton (float in air)
   (*b*) Hydroplankton (float in water)
   (*c*) Cryoplankton (float in ice and snow)
2. **Phytoedaphon** (microscopic soil flora)
   (*a*) Aerophytobionts (aerobic)
   (*b*) Anaerophytobionts (anaerobic) } Bacteria
3. **Endophytes**
   (*a*) Endoxylophytes (Parasites of plants)
   (*b*) Endolithophytes (Algae, Fungi and Lichens)
   (*c*) Endozoophytes (Pathogens on animals)

4. **Therophytes**
    - (*a*) Thallotherophytes (Myxomycetes and moulds)
    - (*b*) Bryotherophytes (Liverworts and mosses)
    - (c) Pteridotherophytes (Vascular cryptogams)
    - (*d*) Entherophytes (annual seedplants) which may be creepers (climbers or erect)
5. **Hydrophytes** (all water plants except planktonic forms)
6. **Geophytes** (Earth plants)
    - (*a*) Geophyta mycetosa (Root and tuber inhabiting fungi)
    - (*b*) Geophyta Parasitica (*e.g.*, ***Rofflesia*,** a root parasite)
    - (*c*) Eugeophytes with bulb, rhizome and root tubers.
7. **Hemicryptophytes** (some thalloid algae, fungi, lichens and rooted creepers, climbers and Rosette plants)
8. **Chamaephytes** (mosses, lichens, leaf succulents, cushion plants, hard grasses, semishrubs and trailing shrubs)
9. **Phanerophytes** (succulent cacti, herbs, liana plants)
10. **Epiphyta arboriela** (Tree epiphyte)

Biological spectrum or Phytoclimatic spectrum

Raunkiaer's system is unitary being based completely on the position and protection of perennating buds during unfavourable seasons.

The characters are structural, essential and adaptive. Furthermore, they provide simple basis for statistical treatment. The array of percentages of life-form classes of a flora of any area composing any floristic community is called the *biological spectrum* or *phytoclimatic spectrum*. Since each life-form class is related to the environment, the biological spectrum is direct indicator of its environment. In biological spectrum, the life-form classes are represented by their percentages. Raunkiaer prepared a normal spectrum, based on sampling of world flora using one thousand entities. The normal spectrum provides a base line from which the departure of percentages of any class in any given flora can be ascertained. The normal spectrum has :

Phanerophytes 46%
Chamaephytes 9%
Hemicryptophytes 26%
Cryptophytes 6%
Therophytes 13%

Generally the biological spectra are worked out and compared with Raunkiaer's normal spectrum.

The percentage of phanerophytes in different floras ranges from zero to over 74% in the tropical rain forest. The higher percentage of phanerophytes is indicative of phanerophytic climate. The higher percentage of therophytes (above 40%) indicates therophytic climate (desert). High percentage of chamaephytes (above 50%) indicates an extremely cold climate. High percentage of hemicryptophytes in temperate forest vegetation indicates for the conditions favourable to the development of extensive grassland. Geophytes (cryptophytes) are abundant in the regions of mediterranean climate and in the broad leaf deciduous forest. The biological spectra of different areas differ from one another and there is no base line for comparison.

There are certain limitations to usefulness of biological spectrum as indicative of climatic condition, because at certain places it does not indicate the environmental conditions, for example, therophytes are abundant in Indogangetic planes where phanerophytic vegetation should actually be dominant. Biotic agencies are the chief causes for changing the biological spectrum in a given floristic zone. Thus comparison of biological spectrum with normal spectrum may sometimes create conclusions and may also lead to wrong conclusions.

As the leaves are essential part and are very much affected by climatic conditions, their shapes and sizes have been taken as important criteria in further classification of different life-forms. Raunkiaer used leaf size as important character in classification, and classified **plants** into the following leaf sizes classes :

Leaf size classes	*Leaf size*
1. Leptophyll	Upto 25 sq. mm area,
2. Nanophyll	From 25 to 225 sq. mm in area the upper limit being 9×25 sq. mm,
3. Microphyll	Area from 225 to 2025 sq. mm (20·25 sq. cm, or $9^2 \times 25$ sq. mm).
4. Mesophyll	Area from $2025 \times 18,225$ sq. mm) (182.5 sq. mm) or $9^3 \times 25$ sq. mm.
5. Macrophyll	Area from 18,225 to 164,025 sq. mm. (1,640·25 sq. mm), or $9^4 \times 25$ sq. mm.
6. Megaphyll	Larger than macrophylls, area over 1,640.25 sq. cm.

EVOLUTION OF PLANT COMMUNITY OR COMMUNITY DYNAMICS

Evolution of plant community on a bare area is quite a prolonged process. This involves a number of stages. Each stage is characterised by particular assemblage of plant populations and dominants. It is difficult to recognise these stages because of the fact that the process of community evolution is continuous. However, these stages can be defined on the basis of their characteristic vegetation. Evolution of plant community involves the following important steps and processes :

(1) **Nudation**. The development of bare areas is initial prerequisite. The naked areas develop either by emersion, submergence, glacial recession, erosion, deposits and climatic change or by biotic agencies.

(2) **Migration including initial colonisation.** When the area becomes bare some plants from the nearby localities move into it in the form of germules, propagule or migrules (structures or offsprings reaching to different places). This process is known as migration. Migration starts when germules leave their parent areas and terminate when they reach to the final resting place. The movement between these two places may complete in one or two steps. It is only by migration, plants from an area are brought into new areas. Several agencies help in the migration of plants to new areas. They are wind, water, animals, man, glacier, etc. Migrules may jump into the new area from all the surrounding localities or from one side only.

(3) **Ecesis**. It is a process of establishment of immigrants. When the migrants enter a new area, they germinate, grow and reproduce there. It is not necessary that all the migrules reaching to the new area must stabilize. The stabilization depends greatly on the conditions prevailing in that area. The first plants growing in the new area are known as *pioneer colonisers*. The germination may be affected by a number of external and internal factors. Dormancy may be a barrier in the germination. Viviparous germination is helpful in the establishment of halophytes in the saline marshy places, as the saline habitat has marked reducing effect on germination.

(4) **Aggregation of germules.** In the beginning, pioneer plants may be present in very small number and they grow far from one another. These plants produce reproductive structures which will be dispersed in the open areas around them and after germination they form their family groups.

In the course of evolution, more new migrules reach in the open areas and become stabilized there. This grouping together of colonising individuals in bare area after migration is termed as *aggregation*. Aggregation may be of two types :

(i) **Simple aggregation**. In this, the germules are aggregated in the group around the parent. This is independent of immigration. It increases the number of individuals of only one species, *e.g.*, *Gloeocapsa*, *Tetraspora*. Falling down of fruits and seeds of the plants just below it is also aggregation.

(ii) **Mixed aggregation**. When the individuals from the family groups migrate away and some more new immigrants are brought by some means into the area under colonisation, it is called mixed aggregation.

(5) **Evolution of community relationships**. When the bare areas become occupied by the individuals of colonising species, they become related with one another. The relationships may be of the following three types :

(i) **Exploitation**. In this, one species lives at the expense of another.

(ii) **Mutualism**. In this, one or both species benefit from the relationship but none suffers.

(iii) **Co-existence**. In this, the species live together in some measures of actual or potential competition for same necessities, such as light, moisture, space and nutrients.

Competition starts among the constituents of vegetation when the supply is inadequate to meet the full requirements of all. Competition may be interspecific or intergeneric. It increases with the increase in the number of individuals in the populations. If the populations over the entire community range are habitually at levels producing interspecific competition, coexistence will be possible only for species best adapted to some recurring variants of the ecological pattern of the community. Competiton is, perhaps, most acute in the early stages of growth when mortality is highest. Between individuals of the same species an equilibrium may be established so that over a wide range of population density of the total productivity is very similar. The reactions vary greatly between the individuals of different species. In perennials, the mode of growth and rate of potential spread play important roles in competition. Competition continues until the vegetation is fully established.

(6) **Invasion**. In the process of colonization, germules of the aggressive and more adapted plants reach to the adjacent area from time to time. There they grow and become established. This process is termed as *invasion* and the new aggressive and more adapted organisms are called *invaders*. Invasion may be intermittent (periodic) or continuous. The invaders establish themselves in the new area either temporarily (partial invasion) or permanently (permanent invasion). New invaders may come either from the areas adjacent to the locality under colonisation or they come from the places in the same locality. These are several barriers to check the invasions. Some of them are as follows :

(*i*) topographic barriers : mountains, valleys, slopes, *etc.*

(*ii*) physical barriers : oceans, lakes, rivers, deserts, *etc.*

(*iii*) biotic barriers : man, animals, insects, *etc.*

(7) **Reaction**. This essentially involves the changes that are brought in the habitat conditions by the plants themselves. This is the effect of interactions between vegetation and habitat. Plants modify the environment particularlys in two ways :

(*i*) by changing the nature and reaction of soil and

(*ii*) by modifying the climate.

Acute competitions in the developing plant communities cause the disappearance of many individuals. The dead remains of colonisers are added to the soil in the form of humus. Humus changes the soil structure to a considerable degree. It also increases the water holding capacity, aeration and mineral contents of the soil.

Shadow of the plants checks the rise of temperature and increases the humidity of the air.

Reaction is continuous process. This leads to the development of such conditions as are less favourable to the growth of previous colonising individuals and more favourable to the new invaders. In this way, reaction plays important role in the replacement of pre-existing plants by the new invaders.

(8) **Stabilization**. Continuous competition and reaction bring about several marked changes in the environment and consequently introduce gradual change in the structure of vegetation. After a long time, some such individuals come and dominate in the area as are least affected with the new changes in the habitat. Climate at this stage plays principal role in determining the nature of community. This process is called stabilization.

(9) **Climax**. The final stage of vegetation development after the stabilization is called climax stage. The dominant species of climax community are nearly in complete harmony with its habitat and environment. Climax community is nearly stable and will not change, so long as the climate and physiography remain the same. However, complete climax is impossible because the community and environment both are changing, *i.e.*, they are in dynamic state.

CLASSIFICATION OF COMMUNITY

Plant communities have been classified in several ways according to particular need or viewpoints. The following criteria have been widely used in the classification of communities :

(1) Physiognomy, (2) Habitat, (3) Species composition and dominance.

Physiognomy refers to the general appearance of plant community. Major plant communities of large area are classified into component communities on the basis of physiognomy. Component communities recognized on the basis of physiognomy are named after the dominant forms of life, as for example, forest, grass land, desert community, etc.

Major communities are sometimes divided into smaller segments on the basis of habitat, mainly on the basis of water content in the habitats. Sometime five different types of component communities can be delineated in a major community on the habitat basis : (1) Wet land commuuity, (2) Wet-mesic community, (3) Mesophytic community, (4) Dry-mesic community, and (5) Dry land community.

Major plant communities are often divided into smaller divisions on the basis of species composition and dominance. Such a classification requires the knowledge of species content of the community, frequency (the regularity with which a species is distributed throughout community), dominance, and fidelity (faithfulness of species to their community). If two areas have got similar communities, the communities are named after dominant organisms or those that show high frequency, e.g., *Betula-Rhododendron-Magnolia* association, Oak-hickory forest.

Clements recognized dynamic nature of community and he developed floristic classification with emphasis on succession, dominance, constancy, and diagnostic species. According to Clements vegetation can be analysed into the following classificatory units in descending sequence.

(1) **Formation**. According to Clements, the major unit of vegetation is plant formation. Plant formation is a great vegetational unit in a region determined by several dominant growth forms, as for example, the forests which are characterized by trees. Plant formation is a product of macroclimate and is controlled and delimited by climate alone. In other words, 'formation occurs in a natural area of essential climatic unity' (Weaver and Clements, 1938). Whittaker is of the opinion that plant fomations are not distinct or concrete vegetational units determined solely by climate, but they are abstract groupings of communities of similar physiognomy (outward appearance of community) and environmental relations. The formation, according to Clements (1938), is a complex organism and as such it arises, grows, matures, and reproduces. Mature vegetational unit which shows no sign of change in its climatic region is termed as *climax community* and changing vegetation units are termed as *seral communities*.

Dansereau (1958) considers the following basic formation types :

(*i*) **Forests**. These are characterised by trees. The forests may be evergreen and deciduous, high and low (mostly above 8 metres) tangled with lianas, heavy with epiphytes or sparse, long lived and some rather short lived, they may harbour little undergrowth or a dense carpet of mosses. Forests of 6 types have been recognised by Dansereau (1958). These are (*a*) tropical rain forest, (*b*) temperate rain forest, (*c*) tropical deciduous forest, (*d*) summergreen deciduous forest, (*e*) needle leaf evergreen forest, (*f*) evergreen hard-woods.

(*ii*) **Woodland**. It is open stand of trees which are as tall as trees growing in forest but scattered rather than clumped.

(*iii*) **Savanna**. It contains low branched, often flat topped small trees (less than 10 metres) and many other woody plants scattered regularly or assembled in small groves. The intervening spaces are often occupied by seasonal grasses (in tropics).

(*iv*) **Scrub**. It is an essentially continuous stand of medium sized compact growing bushy plants separated by bare ground or herbaceous patches.

(*v*) **Prairie**. It is a continuous stand of tall dense grasses which are more than 50 cm. high. They are usually seasonal in distribution. Besides grasses, very few shrubs may be present there.

(*vi*) **Meadow**. It is continuous stand of herbaceous plants, the majority of them being graminoids. Meadows are devoid of woody plants.

(*vii*) **Steppe**. It is a very open stand containing bunch grasses interspersed with low shrubs. Steppe and scrubs or steppe and meadow or even prairie differ each other in respect to the plant coverage.

(*viii*) **Desert**. It is characterised by extremely low permanent coverage. The perennial vegetation (mostly woody or succulent and evergreen) is very sparse and during rainy season the ephemerals may cover the area.

(*ix*) **Tundra**. It consists of a very low woody vegetation, trailing shrubs and cushion plants intermingled with mosses.

(*x*) **Crusts**. These are formed by algae, fungi, lichens on the rocky surfaces or soils.

(2) **Association**. Every climax formation consists of two or more subdivisions which are known as associations, each being marked by more than one dominant species that are peculiar to it Association is regional vegetation in the formation. It is climax of subclimate within the general climate of the formation. Each association is similar throughout its extent in physiognomy, in its ecological structure and in general floristic composition (Weaver and Clements, 1938). Example of association is Oak-Beech association. Developing counterpart of association is called *Associes*. Now the association concept has fallen in disuse and in its place community continuum is gaining popularity. The vegetation is continuous, though differing from place to place. It can not be categorised into well defined units because it is in changing state. Whittaker (1951, '56) asserts that association is not a concrete natural community. L.E. Braun too criticised association concept in a symposium organised by ecological society of America in August 1956. The main points of objections are :

(*i*) That the communities do not have definite limits but intergrade with one another.

(*ii*) That the species which seem to characterize them may extend to other communities, although, probably in different proportions.

(*iii*) That two communities are not exactly alike.

(*iv*) That the vegetation (leaving aside only those places where habitats change abruptly) is continuous, though differing from place to place.

(3) **Faciations**. Each association which fundamentally includes many dominant species consists of two or more subunits. These are called *faciations*. Each faciation may be dominated by two or more dominants, but the total number of dominants in faciation will be lesser than that of *association*. Seral or developing counterpart of faciation is termed as *faceis*. Another local variation of the association is lociation which varies particularly in the composition of subdominants and influence.

(4) **Consociation.** When there is only one dominant in climax community that is known as consociation. Consociations are smaller unit communities whose single dominants still have the life-forms characterising the formation. Such eca (vegetational units) are modified greatly by edaphic conditions, example—Oak or Beech consociation in Oak—Beech association. The developing counterpart of consociation dominated by single species is termed as *consocies.*

(5) **Societies**. Association and consociations can further be analysed into several minor communities which are under the direct influence of local variations of habitat. These minor communities are dominated by one or more species other than the dominants of associations and consociations. These smaller units are called societies. The dominants of societies are sub-dominants of higher econ. Society thus shows dominance within dominance whose dominant species is (or are) subordinate when we consider consociation as a whole. Developing societies are called *Socies*. If socies have got two or more invading species without evident association, they may be called colonies.

(6) **Clans**. In each society may be found two or more smallest climax units. These are called clans. Each clan is a small aggregation of a single but very locally and overwhelmingly dominant species. The seral equivalent is the family derived from multiplication and gregarious growth of single immigrant.

STUDY OF PLANT COMMUNITY STRUCTURE

The special field of synecology which is concerned with the structure and classification of plant community is known as *phytosociology*. The study of structure and composition of plant communities has been developed largely in Europe and Zurich-Montpether school of vegetational analysis led by J. Braun-Blanquet has outlined several methods grouping them into phytosociology. Two sets of characters, viz., *analytic* and *synthetic* are studied in a comumnity at the same time.

Analytic characters

(Hanson, 1950 and Braun Blanquet, 1932), in contrast to synthetic characteristics are those features of community which can be observed or measured directly in each stand. They include kinds and number of species, distribution of species and individuals, vigour, form, number of individuals, height of plants, area, volume, growth rate and periodicity, etc. There are two differnt aspects of vegetational analysis—namely *quantitative* (characters which can be measured more readily than the others), and *qualitative* (which are described and not measured).

Synthetic Characters

Those aspects of community which are based on analytical characteristics and utilise data obtained in the analysis of a number of stands.

A. Qualitative structures of plant community

The qualitative structure and composition of plant community can be described on the basis of visual observations without any special sampling and measurement. In the qualitative characteristics floristic enumeration (species content), stratifiction, aspection sociability, interspecific associations, life forms and biological spectrum, etc., are studied in the field.

1. Floristic composition or species content of community. The study of species content in a community is of paramount importance. The species content of a community can be studied by periodic collection and indentification of plant species for the whole year. This will show the tolerance of each species for different environmental conditions (Hanson, 1950).

2. Stratifiction and aspection. The number of strata or layers in a community can be determined by general observation of the vegetation. If one periodically observes the flora for the whole year, changes in the appearance vegetation may be apparent with the change in the season. This is known as *aspection*. For this phenology of species in relation to different seasons of the year is recorded. On the basis of general observations of the vegetation a number of layers have been distinguished :

L_1—Ground Stratum like moss, thallophytes, lichens etc.

L_2—Herbaceous or ground flora.

L_3—Middle layer or shrubby layer.

L_4—Top layer or canopy layer of trees.

In grasslands even two to three strata may be distinguished.

3. Life-form. On the basis of general appearance and growth, the species of community are grouped into different life-form classes. The chief criteria for recognising life-form classes have already been given earlier in this chapter. On the basis of percentage values of different life-form classes, real nature of habitat and community can be understood.

4. Sociability. In a plant community individuals of the species are not evenly distributed. Individuals of some species grow widely spaced while those of some other species are found in clumps or mats. The space relationship of plants is referred to as sociability. Individuals of some species when growing in clumps are either very weak or they tend to disappear due to hard competition and as such they cannot form big populations. Braun-Blanquet (1951) has recognised five socioability classes which accommodate different types of species.

Class 1. Shoots grow singly.

Class 2. Scattered groups or tufts of plants.

Class 3. Small scattered patches or cushions.

Class 4. Large patches or broken mats.

Class 5. Very large mats of nearly pure population covering the entire area.

High degree of sociability is seen in those plants which produce large number of seeds with high germination percentage, show good survival of seedlings and mature plants and have many adaptive features. From gregariousness of species, conclusions may often be drawn as to the nearness of approach to optimum conditions (Braun Blanquet, 1932). This may explain the importance of the rough determinations of sociability values.

5. **Interspecific associations**. When the plants belonging to two or more different species grow near one another they form a community. This type of association is known as interspecific association. Interspecific association is possible if

(i) the species can live in similar environment,

(ii) the species in question have similar geographical distribution,

(iii) the species belong to different life-forms (this reduces the competition), and

(iv) the plants of one species are related to the plants of other species. The relationship may be obligatory in one or in both the directions.

Interspecific association can easily be observed in the field.

B. Quantitative analysis of Plant Community

The structure of sociological order in any plant community cannot be studied by observing each and every individual of plant species growing in a habitat. It is rather impossible. Therefore, rough estimate of species content of a habitat is made by observing the plant species at different places or sample areas in the habitat. Several methods have been used by ecologists for this purpose which are as follows :

(1) Quadrat method

(2) Transect method.

(3) Loop method.

(4) Pointless or point method.

I. Quadrat Method of Sampling the Vegetation

The quadrat is a square sample plot or unit for a detailed analysis of vegetation. It is actually the sample-plot method of Clements (1898). It may be a single sample plot or may be divided into several subplots. In vegetational analysis, quadrats of any size, shape, number and arrangement may be used. In the study of a forest community quadrats of one-fifth acre are established to include maximum number of trees, while for studying shrubs and grass cover usually the quadrats of smaller sizes are used. For grassland and low herbaceous community, the quadrats of one square metre size or 50 cm × 50 cm size or even 20 cm × 20 cm size may serve the purpose. The shape of quadrat is usually a square (Fig. 5·2 A and B) but rectangular, or even circular ones are used. In some cases rectangular sample plots often give the best results. The ratio of breadth and length in rectangular plots is generally 1 : 2 or 1 : 4 or 1 : 8

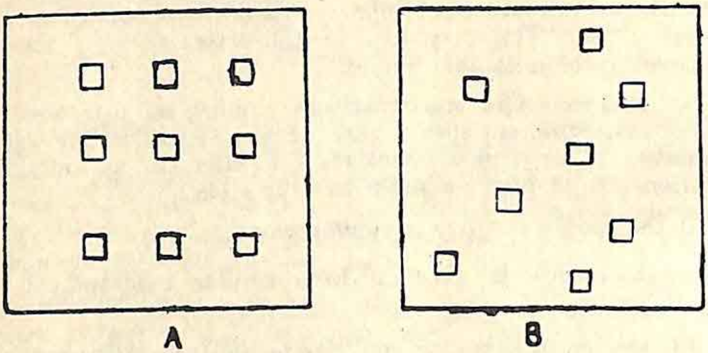


Fig. 5·2 A and B—Arrangement of quadrats in the study area
A—Systematically distributed quadrats.
B—Randomized quadrats.

Kinds of Quadrats. Quadrats are named according to the use. These are of the following types :

(*i*) **List quadrats**. When the organisms encountered in the sample plot are listed by their names, the quadrat is called *list quadrat*. It includes all the species botanically identified or otherwise. A series of list quadrats gives floristic analysis of the community. This is used for studying the frequency of different species.

(*ii*) **Count quadrat or List-count quadrat**. When the species name and the number of individuals of each species found in the sample area are recorded, the sample plot is called *count* or *list-count* quadrat. This type of plot is usually used in forest survey work.

(*iii*) **Cover quadrat**. When the actual or relative coverage is recorded usually as percentage of ground area covered or shaded by vegetation, the sample area is known as *cover quadrat*.

(*iv*) **Chart quadrat**. Quadrats that are mapped to scales to show the location of individuals of species are called chart quadrats. Individual plants are recorded on miniature quadrat on a graph paper often with the help of an instrument called plantograph. This is very tedious work but where long range studies of vegetational changes are being made this method provides a big picture.

So far as the distribution of quadrats in the study area is concerned, statistically reliable estimates are obtained by randomized plots. This is done in the following way.

On the map of the area under study a series of horizontal and vertical grid lines are laid and then these lines are numbered. The number of horizontal and vertical lines are written separately on small square pieces of paper. The paper pieces bearing the numbers of grid lines are placed in two separate beakers (one for horizontal grid numbers and the other for vertical grid numbers) and paper-pieces in each beaker mixed. Then the pairs of numbers are drawn out from the beakers and the position of each plot is located by putting the point given by the paired numbers.

As regards the selection of appropriate size of quadrat for sampling the vegetation, the quadrat selected should be of such small size as may cover the maximum number of species. There is a method for determining the minimal area of the sample plot. In this, sampling is done by using a geometric system of nested plots (Fig. 5·3). In plots of different sizes, number of species found in them are counted and recorded separately. Then the numbers of species found in the plots of different sizes are plotted on vertical axis (O—Y axis) against sample plot sizes plotted on the horizontal axis (O—X axis). The resulting sigmoid curve will be obtained. This is called *species-area curve* (Fig. 5.4). Braun Blanquet (1932), Oosting (1958), Misra and Puri (1954) and many other prominent ecologists of the world have used species-area curve for determining suitable area of the quadrat. Such a curve is obtained because as the size of sample plot is increased the number of species increases in the initial stage but only up to certain plot size, and later the number of new species added declines and finally the curve tends to become horizontal. Thus there is little to be gained by increasing the plot size. The desirable minimal quadrat size is determined by locating the point on curve where line takes horizontal course and joining it to the horizontal axis will indicate the minimal size of small plot.

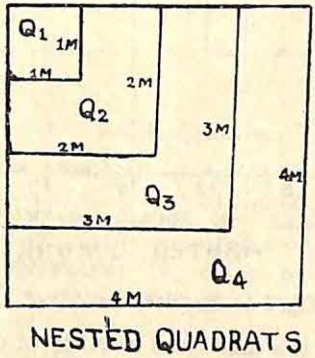


Fig. 5·3—Nested quadrats.

In a well stratified community, the study of different strata is done with the help of different sized quadrats. For the tree and shrub strata large sized quadrats are taken but for ground vegetation small sized quadrats are used. The minimal sizes of quadrat are determined by "species-area-curve" method.

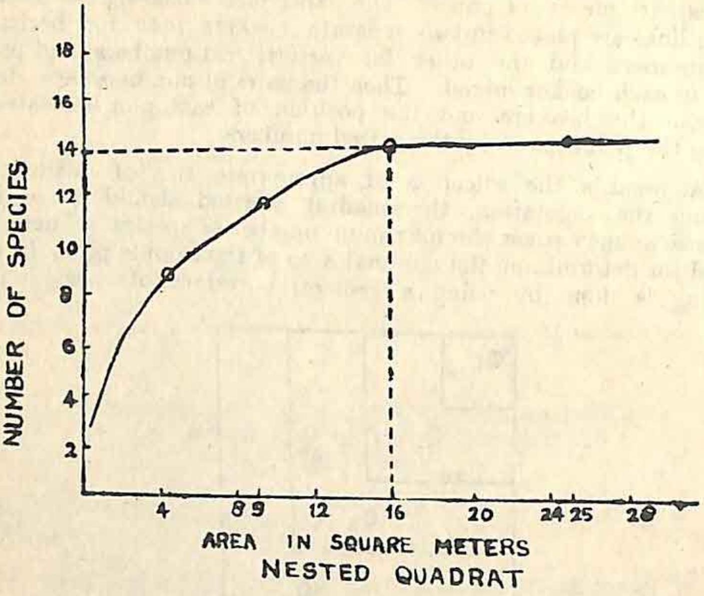


Fig. 5·4—Species area curve.

In the same way the minimum number of quadrats to be taken is also determined.

2. Transect method

A cross-section of an area used as a sample for recording, mapping or studying vegetation is called *transect*. It may be a strip belt or a line across the area of study. The species occurring along these strips or lines are recorded. Because transect is continuous through the study area, it can be applied in studying the gradual and continuous changes in the vegetation along the line or strip with the change in environment. On the slopy area, the transect is laid between two points at different altitudes

The transects are of two types :

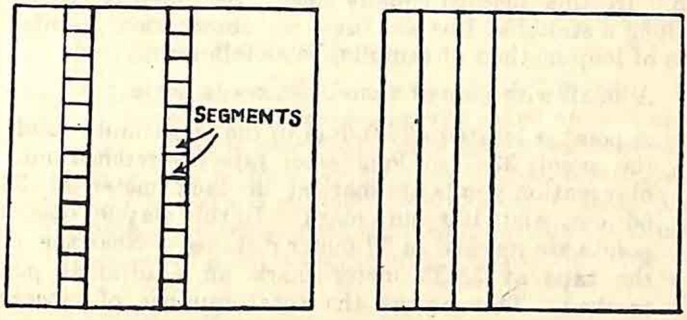
(*i*) Belt transect, (*ii*) Line transect.

(*i*) **Belt transect.** It may be established as follows :

(*a*) The total area of the site to be studied is divided by 5 or 10 to obtain the total sample area.

(*b*) A series of belt transects of pre-determined width and length are laid and the belts are divided into equal sized segments (Fig. 5·5 A). These segments are sometimes called quadrats, but they differ from true quadrats in that each of them represents one observation point. Each segment within a belt is a part and the belt as a whole is one sampling unit.

(*c*) Names of species and number of individuals of each species in each unit are recorded.



BELT TRANSECT LINE TRANSECT

Fig. 5·5 A—Transects.

The belt transect method is used to estimate abundance, frequency, and distribution of species in the community.

(*ii*) **Line transect.** It is one dimensional transect. In this method, observation is taken on lines that are laid randomly or systematically over the study area (Fig. 5·5A). The procedure is as follows :

(*a*) A metric steel tape or steel chain is stretched between two stalks 33·5 metres or one chain apart.

(*b*) The line is considered to be a one centimetre wide belt extending along one side of the tape or chain.

(*c*) The observer moves along the lines and records plant species and the distance they cover along the line transects. For grasses, rosettes and dicot herbs, the distance covered is measured along the line at ground level. For shrubs and tall herbs, the shadow or foliage cover is measured.

(*d*) Twenty or thirty randomly placed lines under most conditions adequately sample the community.

The following informations can be obtained by this method :

(*i*) The number of times each individual species appears along the transect.

(*ii*) The occurrence percentage for each species in relation to the total species.

(*iii*) The total linear distance in cm of each species along the line.

(*iv*) The total distance of intercept by all species per 30 m line.

3. The Loop Method

This is a simple, accurate and quick method for sampling of only grassland and low herbaceous communities. It is used for determining community composition, species frequency and range condition. In this method equally spaced 100 small circles or loops located along a stretched line are used as observation points. The procedure of loop method of sampling is as follows :

(*a*) A small wire loop of 2 cm diameter is made.

(*b*) A point is located at random in the community and from the point 33·5 m long steel tape is stretched out. The observation points are marked in each meter at 33 cm, 66 cm, and 100 cm. mark. In this way 99 observation points are marked in 33 meter distance. Near the end of the tape at 33·33 meter mark an additional point is marked. This brings the total number of observation points to 100.

(*c*) At each observation point wire loop is dropped to the right side of the tape and species encountered in the circle is recorded.

In this method 20 to 30 transects under most conditions adequately sample the community. Since 100 observation points are used in each line, the sum-totals are read as percentage. By this method species content and cover are easily computed.

4. Pointless or Point Method

In this method of sampling observations are taken on the point in the study area where a nail or set of nails touch the ground on grid lines or at random places. There are several point methods of sampling but here only the following two methods will be discussed :

(*i*) Point frame method. (*ii*) Point centre method.

(*i*) **Point frame method**. This method was introduced by Levy and Madden (1933). It is done with the help of point frame. This consists of a scale like frame, supported at the two ends on a pair of legs. The frame consists of 10 equidistant holes that are fitted with about 60 cm long pointers or nails (Fig. 5·5B). The frame is placed one

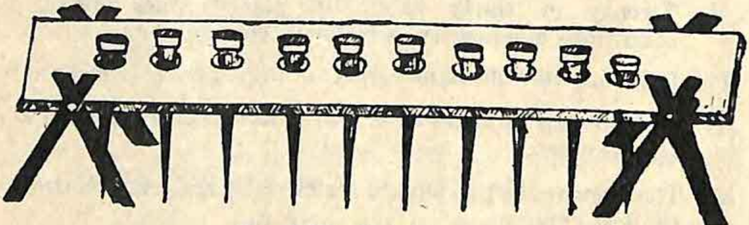


Fig. 5·5B—Point frame

after another at several observation points in the study area and the plant species that are hit by the pointed end of the pointers or nails are recorded. Besides this, the number of times the species are hit, and the total number of points taken are noted. From these values the quantitative structure of community is explained. This method is employed in the study of grassland and low herbaceous communities.

(*ii*) **Point Centre of Quarter method**. It this method of sampling four measurements are taken at each observation point. The observation points can be mechanically placed along a straight line or they can be located at random. Quarter method was first described by Cottam and Curtis (1956). In this method an easy instrument is used which consists of a brass needle or a nail fitted on the top with rubber cork and compass needle (Fig. 5.6). The procedure of sampling is as follows :

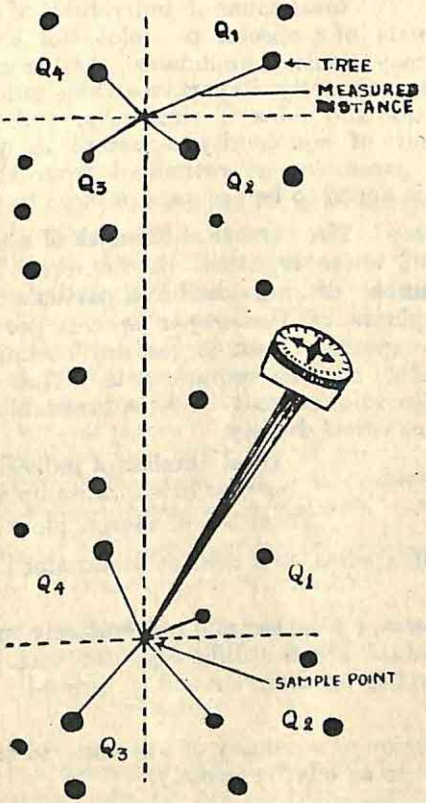


Fig. 5.6—Quarter or Point method of sampling

(*a*) At each observation point the needle is fixed in the ground. This is central point.

(*b*) The working area is divided into four quarters or quadrants by visualizing two grid lines predetermined by the compass at right angles. Both the lines should cross each other at the central point.

(*c*) Now in each of the four quarters plant nearest to the central point is spotted and species recorded. The distance of each plant from the central point is measured and also the basal diameter of the plant measured.

(*d*) Tally at least 50 such points.

Quantitative Structure of Plant Community

Coexistence and competition both are affected directly by the number of individuals in the community. Therefore, it is essential to know the quantitative structure of community. To characterize the community as a whole certain numerical constants called parameter are used. The total count of individuals of each species, mean value of individuals of a species per plot, for example, are parameters. Frequency, density, abundance, shadow and area coverage of species in the community, importance value index, total estimates, index of association and index of similarity, and fidelity of species give a clear picture of community structure in quantitative terms. The value of a parameter as estimated from the samples is the estimate which is hoped to be accurate or close to the real value.

1. Density. The numerical strength of a species in relation to a definite unit space is called its density. The *crude density* refers to the number of individual of a particular species per unit area, *e.g.*, 2000 plants of *Peristrophe* species per acre will be the density of this species. Each organism occupies only the area that can adequately meet its requirements. Thus the density of an organism refers to this amount of area available as living space. This would be ecological density.

$$\text{Density of a species per unit area} = \frac{\text{Total number of individuals of a species in all the sample plots}}{\text{Total No. of sample plots studied}}$$

Density of species in a field is determined on the table on next page.

In some cases, *e.g.* grass and vegetatively propagated plants, the term individual creates difficulty. In such cases each aerial tiller or shoot arising out from the soil is generally regarded as one individual.

The proportion of a density of a species to that of stand as a whole is referred to as relative density.

The following formula is used for calculating relative density of a species :

$$\text{Relative density of a species} = \frac{\text{Total no. of individuals of a species}}{\text{Total no. of individuals of all species}} \times 100$$

Names of species	*Number of individuals in different quadrats each of 1 square meter size*										*Total No. of individuals*	*Density*
	1	2	3	4	5	6	7	8	9	10		
1. *Evolvulus alsinoides*	5	4	7	×	1	3	9	2	8	5	44	$\frac{44}{10}=4{\cdot}4$ plants/m.^{2}
2. *Indigofera sp.*	×	7	6	9	2	4	×	1	5	×	34	$\frac{34}{10}=3{\cdot}4$ plants/m^2.
3. *Peristrophe sp.*	3	1	4	×	×	×	1	2	×	7	13	$\frac{18}{10}=1{\cdot}8$ plants/m^2.
4.												
5.												
6.												

2. **Frequency**. In the community, the individuals of all the species are not evenly distributed. Individuals of some species are widely spaced while those of some other species are found in clumps or mats. The distribution patterns of individuals of different species indicate their reproductive capacity as well as their adaptability to the environment. Frequency refers to the degree of dispersion in terms of percentage occurrence. In order to study the frequency of species in an area, the study area is sampled by any sampling method at several places in desired pattern or at random and only the names, not the numbers, of individuals of species encountered in each sample are listed. The frequency of a species is determined with the help of the following formula :

$$\text{Frequency} = \frac{\text{total no. of quadrats in which the species occurs}}{\text{total no. of quadrats studied}} \times 100$$

Suppose species 'A' occurred in 4 quadrats out of total ten quadrats studied, the frequency of species A will be

$$\frac{4}{10} \times 100 = 40\%$$

If the line or belt transect method is used for sampling then each line or belt is recognised as one quadrat for the purpose of frequency calculation.

If point frame method of sampling is used, the frequency is calculated by the following formula :

$$\text{Frequency of a species} = \frac{\text{Total no. of hits the species secured} \times 100}{\text{Total hits made}}$$

For calculating frequency, the following pattern is adopted :

Species	*Number of sample plots*										*Frequency percentage*
	1	2	3	4	5	6	7	8	9	10	
1. *Evolvulus sp.*	×	×	—	—	×	×	—	—	×	×	$\frac{6}{10}\times100=60\%$
2. *Peristsophe bicalyculata*	—	—	×	×	×	×	—	×	—	—	$\frac{5}{10}\times100=50\%$
3. *Cynodon sp.*	×	×	×	×	×	×	×	×	×	—	$\frac{9}{10}\times100=90\%$
4. *Euphorbia sp.*	×	—	—	—	—	×	×	×	—	×	$\frac{5}{10}\times100=50\%$
5. *Boerhaavia sp.*	—	—	—	—	—	—	—	×	—	×	$\frac{2}{10}\times100=20\%$
6.											

(In the above table occurrence of species is marked by '×')

If the individuals of a species are evenly distributed over the area they may occur in all the sample plots and thus the frequency of species will be 100%. Poorly dispersed species will occur only in a few quadrats and their frequency will be low. This indicates that higher the frequency value of a species in the area the greater will be the uniformity in the spread.

Raunkiaer recognized five frequency classes of plant species in the community on the basis of their frequency percentage. These are as follows :

Class A—1 to 20% frequency

Class B—21 to 40% frequency

Class C—41 to 60% frequency

Class D—61 to 80% frequency

Class E—81 to 100% frequency

Raunkiaer (1934) suggested that the number of species in frequency class A is greater than that of class B ; B is greater than class C, class C is greater, or equal or lesser than class D ; and D is lesser than class E.

$A > B > C \overset{>}{\underset{<}{=}} D < E$, This is also read as Raunkiaer's *'frequency law'*. From the above frequency law it is apparent that the species with low frequency value are higher in number than the species with higher frequency value in most natural communities.

The dispersion of species in relation to that of all the species is termed as relative frequency of a species. Relative frequency is determined by the following formula :

$$\text{Relative frequency of a species} = \frac{\text{Frequency of the species in stand } x}{\text{sum of the frequencies for all species in stand } x} \times 100$$

3. **Abundance**. The estimate number of individuals of a species per unit area is referred to as abundance. To determine abundance, the sampling is done by quadrat or other method at random at many places and the number of individuals of a species is added for all the quadrats studied. The abundance is determined by the following formula :

$$\text{Abundance of a species} = \frac{\text{Total number of individuals of the species in all quadrats}}{\text{Total number of quadrats in which the species occurred}}$$

The abundance is usually expressed by assigning the species to one of the following abundance classes :

Abundance Classes

Classes	Stalks per square meter quadrat
Rare	1 to 4
Occasional	5 to 14
Frequent	15 to 29
Abundant	30 to 90
Very abundant	100+

Abundance refers actually to "*density*" of population in those quadrats in which a given species occurs. In low form of vegetation like grasslands abundance can be regarded by uprooting the plants.

4. **Cover**. The cover implies the area covered or occupied by the leaves, stems and flowers, as viewed from the top. The coverage is studied at the *canopy level* and at the *basal region*. In forest, where several strata are well marked, each layer of vegetation is considered separately for measuring the coverage. Basal cover is best expressed as the basal area, the ground actually covered by the crowns or by stems penetrating the soil. In forest the basal area is the cross section area of a tree measured at 4·5 feet above the ground. (cross section area of a tree at breast height). It is estimated by point method of sampling (quarter method). In grasslands, estimate of total spread of foliage has little meaning. Basal area in such cases refers to the coverage of ground one inch above the ground surface by stems and leaves. It is also called *herbage cover* (Fig. 5·7). The coverage can be measured by quadrat method, transect method and point method of sampling. Basal coverage of tree is measured at breast height. Basal area of tree is calculated by the following formula :

$$\text{Basal area per tree} = \frac{\text{Total basal area}}{\text{number of trees}}$$

The area of coverage is used to express the dominance. The higher the coverage area the greater is the dominance. The average basal area is calculated out of average cross section area of stem penetrating the soil. The average area of one stem multiplied by the density (no. of individuals per unit area) gives the basal cover per unit area.

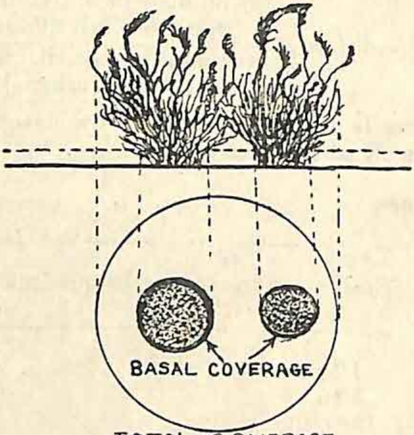


Fig. 5.7. Herbage cover of two clumps of grasses. Basal coverage of each clump one inch above the ground level shown by shaded smaller circles and total coverage by large circle.

Relative dominance (R.D.) is the proportion of the basal area of a species to the sum of the basal coverage of all the species in the area.

$$\text{Relative dominance of a species} = \frac{\text{Total basal area of the species in all the quadrats}}{\text{Total basal area of all the species in all the quadrats}} \times 100$$

5. **Total estimate.** Although abundance and coverage have their own importance in the community structure, yet they can be combined in a community descripton as total estimate. It is probably the best method for obtaining a complete general picture of a plant community. Total estimate (abundance plus coverage) scale as suggested by Braun-Blanquet is as follows :

+ Individuals of a species very few ; coverage very poor.

1. Individuals of a species in plenty ; but coverage small.

2. Individuals numerous if small and a few if large ; coverage 5% of the total area.

3. Individuals few or many ; coverage 25 to 50% of the total area.

4. Individuals few or many ; coverage 50 to 75% of the total area.

5. Plant species over 75-100% of the total area.

6. **Association Index and Index of similarity**. The interspecific association can be evaluated by association index and also by calculating the index of similarity. The index of similarity is utilized to compare two coexisting groups.

Suppose, out of 100 quadrats studies species A is encountered in 90 quadrats and species A in association of another species B is found only in 40 quadrats the association index of species A is calculated by dividing the total number of quadrats in which A occurred in association with B by the total number of quadrats in which species A is found $\left(\frac{40}{90}=0{\cdot}44\right)$

Index of similarity is calculated as follows :

Suppose that in one group of coexisting species the number of plant species is 30 and in the other group the number of plant species is 20 and in first and second groups 15 species are common

$$\text{Index of similarity}=\frac{2\times\text{no. of common species}}{\text{Total number of species in both associations}}\times 100$$

$$=\frac{2\times 15}{20+30}\times 100$$

$$=\frac{30\times 100}{50}=60$$

7. **Importance Value**. In any highly heterogeneous plant community data of frequeucy, density, abundance, and cover of species do not yield total picture of ecological importance independently. The overall picture of ecological importance of a species in relation to the community structure can be obtained by adding the values of relative density, relative dominance, and relative frequency. This total value out of 300 is called *Importance Value Index* (IVI) of the species. Once the importance values have been obtained for the species within the stands, the stands can then be grouped by their leading dominants according to the importance values and the groups are then placed in a logical order based on relationships of several predominant species. The dominants are arranged always in the order of decreasing importance values.

The importance of IVI was first pointed out by Curtis and McIntosh (1951). The IVI, as pointed out earlier, gives complete picture of sociological character of a species in the community but it does not give the dimension of relative density, relative dominance and relative frequency. The individual as well as combined aspects of the position of a species in the community structure can be shown with the help of phytographs. In one type of phytograph a circle is made and then the circle is divided into four equal quarters by two radial lines lying at right angles to each other. Three

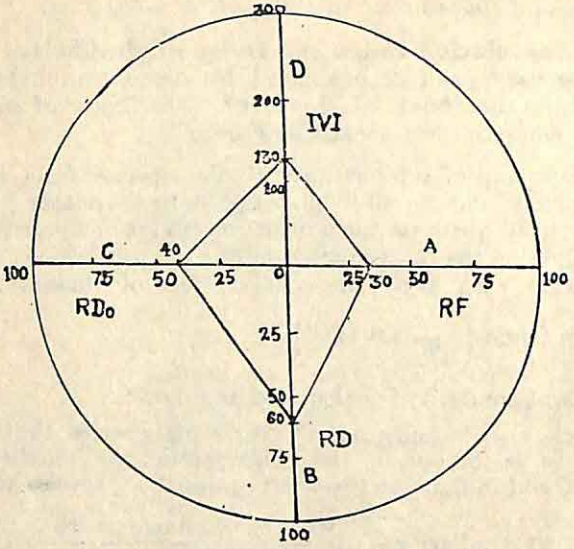


Fig. 5·8. Phytograph of species with Relative frequency (RF) 30%, Relative density (RD) value 60%. Relative dominance (RD_0) value 40% and Importance value index 130.

radii from centre to circumference are divided into 100 segments and the fourth radius is divided into 300 parts (Fig. 5·8). On radius A is marked the value of relative frequency, on radius B is marked the value of relative density, on radius C is marked the value of relative dominance and IVI on 0—300 scale. All these points on different radii are joined by lines. Thus, a phytograph illustrating the sociological characters and IVI of individual species is obtained.

Synthetic Characters

Synthetic characters describe the make-up of a community. The chief synthetic characters used and advocated by Braun Blanquet (1932), Cain (1932) and Nichols (1930) are (1) Presence, Constance and Fidelity.

Fidelity. The term fidelity refers to the faithfulness of a species to its community. In the community, there are different types of species. Some plant species are confined to one particular community and they are called indicator species. Some can flourish in several communities. According to Hanson (1950), it is a measure of ecological amplitude, Pandeya (1960) observes that characteristic species having high fidelity value have *low ecological* amplitude. Ecological amplitude of a species or its tolerance (Good, 1947) is the capacity of grow and reproduce within a certain range of environmental conditions. Fidelity of a species is expressed in relation to a particular community. A species may have high fidelity for one community and a low fidelity for another. Braun-Blanquet and Pavillard (1925), and Oosting (1956) recognised the following classes of species on the basis of their fidelity.

Fidelity Classes	Characters
Class—1	**Strange species** or accidentals which are either intruders from other community or relics from other successional stages.
Class--2	**Indifferent species** companions which have no preference or affinities for any community.
Class—3	**Preferential species**, that may be found in several communities but have affinity for only one community.
Class—4	**Selective species** which may occur rarely in other communities but have strong affinity to one particular community.
Class—5	**Exclusive species** which occur exclusively or almost exclusively in one community.

Species of 3rd, 4th and 5th fidelity classes are called characteristic or key species of the community.

Presence. It indicates nearly the presence of a species in a stand. It is generally expressed in a scale of 1 to 5.

(*i*) *Rare*, 1% to 20% of stands examined
(*ii*) *Seldom present*, 21-40% of stands examined
(*iii*) *Often present*, 41-60% of the stands examined
(*iv*) *Mostly present*, 60 to 80%
(*v*) *Constantly present*, 81 to 100%

Constance. It is the degree of "presence" in a unit area (sample area) instead of the whole stand. It actually improves the method of *presence* study, otherwise there is no fundamental difference between *presence* and *constance*. It is generally determined from frequency and the following 5 constance classes have been recognised.

con. 1—1 to 20% frequency
con. 2—21 to 40% ,,
con. 3—41 to 60% ,,
con. 4—61 to 80% ,,
con. 5—81 to 100% ,,

QUESTIONS

1. What is plant community ? Write an essay on composition of plant community.

2. What is structure of plant community ?

3. Describe Raunkiaer's life form classes of plant community.

4. Explain how a plant community has evolved.

5. Describe the various classificatory units of plant community.

6. Describe the various methods of studying plant community structure.

7. Write short notes on the following :

Synecology, Ecotone, Biological spectrum, Ecesis, Consociation, Evolution of plant community, Density and frequency.

6

PLANT SUCCESSION

"Vegetation is dynamic, an ever changing complex, now appearing quiescent and in complete equilibrium with the habitat, now displaying an obvious evidence of change" says E. Lucy Braun (1956). Observation of the natural changes in vegetation long ago resulted in the concept of succession. Under natural conditions the vegetation occupying a given habitat is called plant community. Since the community is not stable, it passes through many developmental stages in definite sequence and in definite direction generally from simple to complex and rarely from complex to simple. The gradual replacement of one type of plant community by the other is referred to as *plant succession*. According to Odum E.P., "plant succession is an orderly process of community change in an unit area". Salisbury defines plant succession as follows :

"Plant succession is a competitive drift in which at each phase until the climax, the constituent species render the habitat more favourable to their successors than to themselves.

Clements gave a very simple definition of plant succession. According to him, "succession is a natural process by which the same locality becomes successively colonised by different groups of communities."

Succession is a complex universal process which begins, develops, and finally stabilizes at the climax stage. The climax is the final mature, stable, self-maintaining and self-reproducing stage of vegetational development in a climatic unit. Succession is generally progressive and thus it brings about—

(1) progressive changes in the soil conditions or habitats. These changes bring the habitat from extreme to optimum conditions of plant growth, and

(2) progressive changes in the life forms or phiads.

Causes of Succession

The main causes of succession are as follows :

(1) Climatic causes

(2) Topographic causes

(3) Biotic causes.

1. **Climatic causes**. Plants cannot adjust with the long range variations in the climate. The fluctuating climate sometimes leads the vegetations towards total or partial destruction and, as a result, the bare area develops which becomes occupied by such plants as are better adapted for changed climatic conditions. Drought, heavy snowfall, hails and lightnings are some of the important factors for causing the destruction of vegetation.

Sometimes new bare ground is formed by emersion of land from the bodies of water (ponds, river etc.).

2. **Topographic causes**. These are concerned with the changes in the soil. The following are two important soil factors which bring about changes in the habitat.

(*i*) **Erosion of the soil**. Sometimes surface soil is removed by a number of agents, such as the wind, water currents, and rainfall. This process is known as soil erosion. In the process of erosion new and bare area is exposed in which new plant communities begin to appear one after another.

(*ii*) **Soil deposition**. It is one of the important causes that initiates succession. Soil deposition results owing to heavy storms, glaciers, snowfalls and landslides. If the deposition of soil takes place over an area already covered with vegetation, the plants occurring over there may be suppressed and destroyed. Deposition results in a new bare area on which succession of vegetation starts.

3. **Biotic causes**. Many biological or living agencies also affect the vegetation in many respects. Grazing, cutting, clearing, cultivation, harvesting, and deforestation, all caused by living agencies, are directly responsible for vegetational change. The parasitic plants and animals also affect the vegetation and destroy it.

Succession and Climax Concept

Plant succession is an orderly change of vegetation. It involves gradual and successive replacement of one plant population by the other. Any concrete example of plant succession taking place on a particular habitat is termed as sere, its various intermediate stages are called the seral stages and communities representing these stages are called the seral communities. Though the seral communities are not clearly distinct, yet they are recognised only because of some dominant plant species growing in them. The first plants which appear on the bare habitat are called pioneer plants. Actually speaking, plant succession is not a series of steps or stages but is continuous, and very slowly changing complex. It is dynamic process. The replacement of vegetation takes place individual by individual. There is no jump from one dominant community to other. Dominant species of one community will persist along with some new migrants for several generations in a given area and bring about several changes in the habitat by their deeper shades and leaf litter. When the habitat becomes extremely non-tolerable for the existing plants then the plants of next community, that are well suited to that habitat, will come and become dominant. After several such changes, a stage may come when the habitat becomes occupied by most tolerant species that can reproduce and perpetuate well. Thus, the process leads to establishment of climax community ; a mature, dominant, self-maintaining and slow changing plant community. Climax dominants are the species best adjusted to habitat and are able to take possession of the habitat and hold it against the new invading species. The treatments of climax and succession in Clementsian ecology imply the following assumptions about the orderliness of vegetation :

(1) The succession is an orderly growth process. Succession beginning in different environmental conditions finally reach to similar climax.

(1) The climax is determined only by climate, consequently climax and climatic region must correspond.

(3) The vegetations consist of climaxes and their successional conditions are clearly distinguishable.

Whittaker (1953) says that "successional processes give an impression of relative irregularities and disorderliness in detail together with a degree of orderliness in general pattern and trend".

Clements (1928) considered the climax formation as adult organisms, the fully developed community of a region, of which all other communities are the stages of development. Since the climate alone determines the climax formation, there is one true or climatic climax in a climatic region. The climatic climax is achieved where physical conditions of the substratum are not so extreme as to modify the effects of the prevailing regional climates. Sometimes the climax is greatly modified by the physical conditions of soil, such as its topography and water content. Such a climax is known as *edaphic climax*. Relatively stabilized vegetation other than climatic or true climax may be produced in a given region because of distinctive soils or other habitat characteristics. These are referred to as developmental communities.

Sometimes the vegetation is prevented from reaching to the actual climax stage by the factors other than climate, as for example, fire, cutting, grazing, flooding, etc. Thus, the vegetation which is in the imperfect stage of development, is held indefinitely in stages preceding to real climax either by natural or by artificial factors : This type of imaginary climax is termed as *sub-climax*. Such plant communities would tend to reach real climax state if the causative factors are removed. Sometimes many disturbances cause modification or replacement of the true climax and consequently a modified sub-climax is formed which is termed as *disclimax*. If temporary change of the climate stops the development of vegetation before it has reached to the expected climax, it forms *preclimax*. Sometimes the environment changes in such a way that the vegetation progresses beyond the expected climax stage. The new climax, thus formed, is termed as *post-climax*.

Monoclimax and Polyclimax theories

As regards the number of climaxes in a given habitat or climatic region, there are two different schools of thought. These are as follows :

(*i*) **Monoclimax theory**. According to Clementsian school, *there develops only one true climatic climax in a particular climatic region.* This concept is generalised as monoclimax theory.

(*ii*) **Polyclimax theory**. The second school of thought holds the view which is opposite to monoclimax concept. *It defines climaxes as the stabilized and self-maintaining plant communities and considers that a number of climaxes may exist in a given area.*

"The essential difference between monoclimax and polyclimax approaches seems to be the relative emphasis", says Whittaker (1953). According to him, those who support the monoclimax theory emphasize the esssential unity of climax vegetations in a given area with allowance also for stabilized plant communities other than climax, but the exponents and supporters of polyclimax concept emphasize the inherent complexity of climatic climax with allowance also for prevailing climax communities which characterize the vegetation of given area and express their relations to climate."

Clements' monoclimax theory has been severely criticized in recent years on the ground that in the theory regionally prevailing undisturbed vegetation occupying the largest part of the land surface was regarded as real climax and other stabilized plant communities in the same area were recognised as subclimaxes which only theoretically could be replaced by the climax.

Braun, L.E. does not believe in monoclimax concept and comments "*to me monoclimax seems impossible.*" He supports polyclimax idea but that too seems questionable to him. While working on the 'Deciduous forests of Eastern-north America' in 1950 Braun found many intergrading communities among which some were in the developing state and the others had reached to the climax stage, some were very local in occurrence and extent (regional climaxes) and others recur frequently over a big geographic extent (edaphic or topographic climaxes). Thus, his observations fully support the polyclimax idea. Again in the year 1956 in the paper "Development of Association and climax concept", Braun supported the polyclimax idea and said, "the prevalence of any particular climax type may be due to control of climate ; it may be related to the history of erosion cycles and past climate ; it may be due to state of development of climax communities or more likely due to a combination of all.'

The monoclimax theory, of course in modified form, has recently been expressed by Dansereau (1954) and Walter (1954). Oosting, Henry J. of Duke University in his book, "Study of Plant

Communities", mentions that polyclimax theory is more practical. Nichols (1923) also expressed the same view. British ecologists under the leadership of Tansley maintained a general skepticism of monoclimax concept. Russian ecologists also have similar belief.

Smithusen 1950), Whittaker (1951, 53), and many other American ecologists support climax pattern or polyclimax concept and all believe in the fact that the climax state is determined by the environments of individual plant communities and not by regional climate ; the latter identifies the climax as a community steady state and substitutes 'prevailing climax' for climatic climax.

KINDS OF SUCCESSION

Depending upon the nature of bare area on which it develops, the succession may be of two kinds : *primary* and *secondary*.

1. **Primary succession**. When the succession starts on the extreme bare area on which there was no previous existence of vegetation it is called *primary succession* or *presere*. This succession starts in the areas of extreme conditions and the process terminates after a long series of intermediate stages.

2. **Secondary succession**. This type of succession starts on the secondary bare area which was once occupied by original vegetation but later became completely cleared of vegetation by the process called denudation. This denudation process is brought about by the destructive agencies, such as fire, cultivation, strong winds, and rains. When the existing vegetation of an area becomes completely destroyed by destructive agents, it becomes naked or bare. Such a bare area is termed as denuded area or secondary bare area. The succession progressing on such an area is also termed as *subsere*. Secondary succession has fewer stages than the primary succession and the climax is reached very quickly in the secondary succession. These primary and secondary successions may be of the following types :

(*a*) **Hydrosere**. The plant succession which starts in the aquatic environment is called "hydrarch." A series of changes taking place in the vegetation of hydrarch is called hydrosere.

(*b*) **Halosere**. It is special type of sere which begins on a salty soil or in saline water.

(*c*) **Xerosere**. When the vegetational succession develops in xeric or dry habitat, it is called xerarch or xerosere. Xerosere may be of two types :

(*i*) **Psammosere**. It refers to the vegetational succession that begins on the sandy habitat.

(*ii*) **Lithosere**. It refers to the succession that occurs on the rock surface.

(*d*) **Serule**. It refers to the miniature succession of micro-organisms such as bacteria and different types of fungi on the fallen logs of decaying wood, tree bark, *etc*.

Irrespective of the types of succession, all the seres generally lead the plant communities towards the climax stage of mesic community (mesophytic or mixed mesophytic forests).

HYDROSERE

It is succession occurring in the aquatic environment. Such a type of succession does not necessarily lead the aquatic communities toward the development of land communities. If the body of water is large and very deep or if there are very strong wave action and other powerful physical forces, the succession results in a stable aquatic community in which any considerable further change is hardly recognisable. Succession is recognisable only if the colonisation of plant communities takes place in artificial small and shallow ponds, lakes, etc., where wave action speeds up the process by allowing the erosion of soil towards edge regions. In this way, the filling process also speeds up quickly and consequently the body of water disappears within few years time. Fig. 6·1 illustrates the different types of vegetation at different depths in a pond ; floating plants in the central region ; rooted hydrophytes in shallow region, amphibious plants in the marginal mud and trees developing in dry habitat. Different steps of succession of vegetation taking place in a pond have been illustrated by a series of diagrams in Fig. 6·1.

The pioneer stage of hydrosere consists of hydrophytic species. In the initial stage, the submerged aquatic vegetation develops in the regions of ponds or lakes where water depth is about 10 feet or more. The pioneers are *Elodia*, *Potamogeton*, *Myriophyllum*, *Ranunculus*, *Utricularia*, *Ceratophyllum*, *Vallisneria*, *Chara*, etc. These plants form tangled mass and have marked effects upon the habitat.. When these plants die their remains are deposited at the bottom of the ponds or lakes. The eroded soil particles and other transported materials are also deposited at the bottom. This gradually raises the bottom of the ponds and lakes up. As this process of stratification progresses, the body of water becomes more and more shallow, consequently the habitat becomes less suited for the submerged vegetation but more favourable for other plants.

When the depth of water reaches to about 4 to 8 feet, the submerged vegetation starts disappearing from its original place and then the floating plants make their appearance gradually in that area. In the beginning the submerged and floating plants grow intermingled but in the course of time the submerged plants are replaced completely. The most tolerant species in the area are able to reproduce and perpetuate. Their broad leaves floating on the water surface check the penetration of light to deeper layer of water. This may be one of the main causes responsible for the death of submerged plants. Due to continuous interaction between plant communities and aquatic environment, the habitat becomes changed chemically as well as physically. More water and air borne soil and dead remains of plants are deposited at the bottom. Thus the substratum rises up in vertical direction. Important floating plants that replace the submerged vegetation are *Nelumbium, Trapa, Pistia, Nymphaea* and *Limnanthemum*, etc.

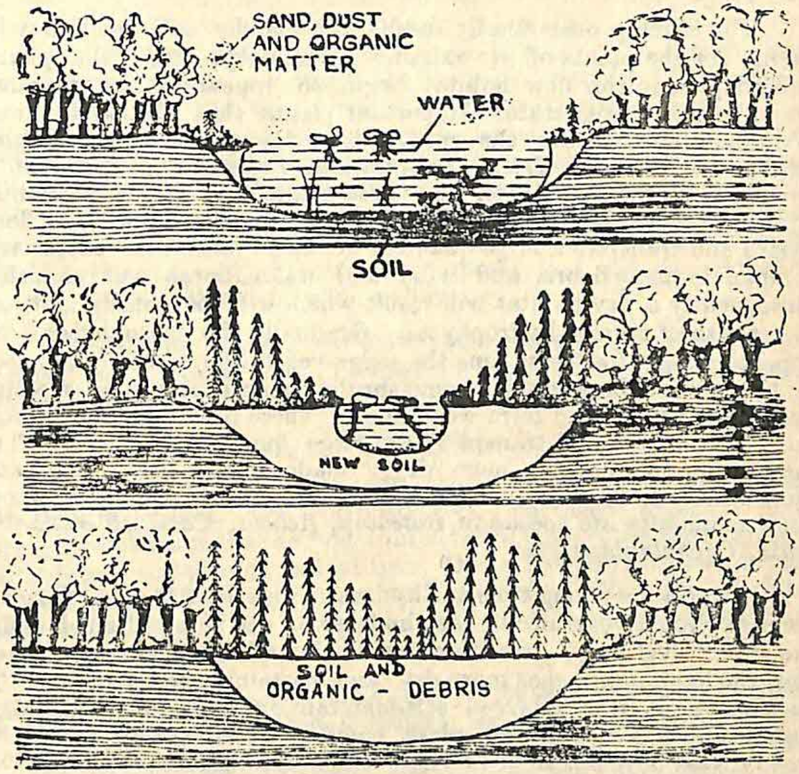


Fig. 6·1—Diagram of community succession in an open pond

When the ponds and lakes become too shallow (water depth one to three feet) and the habitat is changed so much that it becomes less suiting to the floating plants, some other plants which are well adapted to new environment will then come. Under these conditions, the floating plants start disappearing gradually and their places are occupied by amphibious plants which can live successfully in aquatic as well as aerial environment. Important examples are *Bothrioclova, Typha, Phragmites* (Rheed), etc. The foliage leaves of such plants are exposed much above the surface of water and roots are generally found either in mud or submerged in water. The foliage leaves form a cover over submerged and floating plants and thus they cut off light from the plants underneath them. Under such conditions neither submerged nor floating plants can survive. Further deposition of soil and plant debris at the bottom reduces the depth of water and makes the habitat less suitable for the pre-existing plants. When the bottom reaches very close to the water surface many secondary species, such as of *Polygonum, Sagittaria* etc. make their appearance. Later, they also bring about such reactions by which the habitat becomes less suitable for most of the existing species, and consequently new successional step will appear.

The filling process finally results in a marshy soil which may be too dry for the plants of pre-existing community. Now the plants well adapted to this new habitat begin to appear in the previous community in mixed state. Important plants that are well suited to marshy habitat are the species of sedge (*Carex* and *Juncus*), species of *Themeda, Iris, Dichanthium, Eriophorum, Companula, Cymbopogon, Equisetum*, etc. As these plants grow most luxuriantly in the marshes, they modify the habitats in several ways. They absorb and transpire a large quantity of water and also catch and accumulate plant debris and wind and water borne soil particles, consequently a dry habitat will result which will be totally unfit for the growth of normal hydrophytes. Gradually the mesophytes start appearing and after some time the sedge vegetation is totally replaced by them. In the beginning some shrubby plants, and later medium sized trees appear and form woodlands. These plants produce more shade and absorb and transpire very large quantity of water. Thus they render the habitat more dry. Shade loving herbs may also grow under the trees and shrubs. The prominent plants of woodland community are species of *Buteazon, Acacia, Cassia, Terminalia, Salix, Cephalanthus*, etc.

After a very long time the hydrosere may lead to the development of climax vegetation. As the level of soil is raised much above the water level by progressive accumulation of humus and soil particles, the habitat becomes more dry and certainly well aereated. In such a habitat, well adapted self-maintaining and self-reproducing, nearly stable and uniform plant community consisting mostly of woody trees develops in the form of mesophytic forest.

In the climax forest, all types of plants are met with. Herbs, shrubs, mosses and shade loving plants represent their own communities. Trees are dominant and they have control over the entire vegetation. Bacteria, fungi, and other microorganisms are more frequently found in the climax vegetation. They react upon the habitat and make the soil rich in the organic materials. At the climax stage, a complete harmony develops between plant community and habitat. It is now clear that whole sere is a continuously but gradually changing complex in which the changes are forced by biotic, topographic or climatic factors. It is very slow process that cannot be observed in nature. It may require thousands of years to reach the climax state. One can, however, observe the sequence of hydrosere as he moves in the lake or pond from the region of greatest depth towards the shallower margin.

XEROSERE (A SUCCESSION ON BARE ROCK SURFACE)

Like hydrosere, a xerosere also completes after a series of several orderly steps ; each seral stage being characterised by peculiar type of plant community and reaction.

Xeric succession commonly occurs on bare rock surfaces resulting from glaciation or from erosion by wind and water. The rocky habitat shows many extreme xeric conditions. As the rock is directly exposed to sun, the temperature of rock surface goes very high. There is no water and nutrient holding device on the exposed smooth surface of rock. In such a xeric habitat only those plants can survive which can resist the extreme drought. The pioneer colonisers on the bare area are crustose lichens which occur on the rock surface in the form of membranous crusts. Important crustose lichens are *Rhizocarpus*, *Lacidea* etc. These plants grow only when water becomes available in the habitat. In dry periods, the pioneers, though they appear to be desiccated, remain alive. Their spongy nature enables them absorb excess amount of water and minerals. These lichens migrate through their spores and soridia and their migration is facilitated by wind and water.

The lichens secrete carbonic acid in excess. That acid is formed when excess CO_2 liberated in respiration combines with water. The reaction completes in the following way :

$$CO_2 + H_2O \rightarrow H_2CO_3 \text{ (Carbonic acid)}$$

The carbonic acid reacts with the rocky materials and loosens the rock particles. The corroded rock particles together with decaying lichens make the first thin layer of soil on the rock surface. Nitrogenous compounds formed from the atmospheric gases in the lightening are brought to the soil by rains. Now the habitat becomes less fit for the existing plants and consequently primary colonisers begin to disappear from there.

After accumulation of little soil and humus, the rock surface, previously occupied by crustose lichens, now becomes covered with xeric foliose and fructicose lichens, *e.g.*, *Dermatocarpon*, *Parmelia*, *Umbilicaria* etc. These lichens have delicate leaf like thalli which cover the rocks and overshadow the pre-existing crustose lichens. When the supply of light is cut off, the crustose lichens begin to die. Foliose lichens absorb and accumulate water and minerals and check evaporation of surface water. They also secrete carbonic acid which further pulverizes or loosens the rocks into small particles. The water retaining capacity of the habitat increases with the further accumulation of soil particles and humus. Gradually the conditions become less favourable for the existing foliose and fructicose lichens. When the habitat is changed, the existing foliose lichens start disappearing and in that area xerophytic mosses grow and become dominant. These plants usually grow in the crevices and depressions of the rocks where enough rock particles, humus and moisture are accumulated. Like lichens, those mosses are also adapted to survive in extreme drought. These xerophytic mosses develop rhizoids that penetrate deep into the rocky soil. They cover the previous lichens and successfully compete with them for water and mineral nutrients. The decaying older parts of mosses form a thick mat over the rock surface. As this mat becomes more thick, it increases the water holding capacity of soil. Thus the habitat becomes relatively more wet. Now the next seral community may replace the moss community.

When the soil increases in thickness, the herbaceous vegetation, which consists mainly of annual and perennial herbs develops very quickly. Increased moisture content of the soil favours the growth of herbs. The roots of these plants penetrate down almost to the level of unpulverized rock where they secrete acids and accelerate the process of rock disintegration. In this way, the thickness of soil on the rock surface increases to a considerable extent. Decaying leaves, stems, roots and other parts of the plants become deposited on the soil surface in the form of humus. This further increases the water holding capacity of the soil. These reactions make the habitat more suited for woody plants than to the existing herbs.

With the change of habitat, herbaceous vegetation also shows the sign of degeneration and xerophytic shrubs gradually occupy the area. Roots of shrubs also reach to the surface of unpulverized rocks and corrode sufficient quantity of rock particles which make the soil more massive. Decaying leaves, twigs and roots of these shrubs also enrich the soil with humus. These important reactions bring about such conditions in the habitat, that are most suited to the trees rather than to shrubs and herbs. Now the xerophytic trees invade the area which has been occupied previously by shrubs. The first trees growing in such areas are dwarf and widely spaced. With the increase in the water holding capacity of the soil these trees gradually disappear and subsequently the mesophytic types will develop. The trees are deeply rooted and their roots are profusely branched, hence they can absorb sufficient quantity of water and nutrients. These mesophytic trees grow densely and become dominant because their seedlings are shade tolerants. In the shade of mesophytic trees, some shade loving herbs and shrubs which are well adapted to humid atmosphere and moist soil also appear and they form their own communities. After very long interval when complete harmony develops between the plant communities and their environments the climax stage is established which remains unchanged unless some major environmental changes disturb it.

Successions on the bare areas do not always advance exactly in the sequences described above. Suppose, on a bare rock sand and gravels are deposited and succession starts on it, then the possibilities are there that some beginning stages may not develop at all and herbs, shrubs or even trees may appear as initial colonizers on such a habitat.

Succession on the sand-dunes starts with drought resistant grasses. The grass vegetation is followed by shrubs and trees. Primary succession on open land may lead to a grassland vegetation rather than a forest climax.

SOME EXAMPLES OF SECONDARY SUCCESSION OR SUBSERES

Subsere develops usually in settled areas which are greatly modified by the activities of man. It has fewer stages and it reaches to the climax state more quickly than the primary ones.

This type of succession may develop on any secondary bare habitat, such as burnt lands, lumbered lands, disturbed agricultural lands etc. The secondary bare area develops after the complete destruction of previous vegetation growing over it.

Secondary succession on burnt or lumbered bare areas may start with annual grasses and other herbs This pioneer stage in due course of time will be replaced by perennial shrubs and trees. If such an area remains undisturbed by biotic agencies, climax woodland will be established.

From the study of succession, it becomes clear that the vegetation is not merely a haphazard covering of land by plants but it represents an orderly process of colonisation governed by interaction of plants and environments. It is mainly due to succession that the landscapes are changing continuously, some very quickly while others very slowly.

The knowledge of principles of succession is helpful in the management of forests, agricultural lands, mountain ranges and wild life areas.

QUESTIONS

1. What is plant succession ? Write an essay on plant succession.
2. What is sere ? Describe the various successional stages of hydrosere.
3. Describe the various development stages of pond studied by you. Give 4 examples of each stage.
4. Write short notes on the following :
   sere, causes of succession, climax; xerosere, secondary succession.

7

PLANT ADAPTATIONS

Plants bear full impression of the environments in which they grow. Warming (1895) in his book of ecology had realised for the first time that the influence of controlling or limiting factors upon the vegetation was of paramount importance in the study of ecology. He classified plants into several ecological groups on the basis of their requirements of water and also on the basis of nature of substratum on which they grow.

Warming classified plants on the basis of nature of substratum (soil) into the following groups :

(1) Plants of acidic soil (**Oxylophytes**)

(2) Plants of saline soil (**Halophytes**)

(3) Plants growing on the sand (**Psammophytes**)

(4) Plants growing on the surface of rocks (**Lithophytes**)

(5) Plants growing in the crevices of rocks (**Chasmophytes**).

Epiphytes are not included in the above classification because of the fact that they do not have permanent connection with the soil.

Warming's second classification of the plants is based on their water relations. The supply of water to the plants and regulation of transpiration are the factors that evoke greatest difference in plant forms and plant life. On the basis of their water requirement the plants have been classified as follows :

(1) **Hydrophytes** : Plants growing in or near water.

(2) **Xerophytes** : Plants adapted to survive under condition of very poor supply of water in its habitat.

(3) **Mesophytes** : Plants growing in an environment which is neither very dry not very wet.

The detailed description of some important ecological groups is given here.

HYDROPHYTES

(*Greek, Hudor*=water and *Phyton*=Plant ; water plant)

Plants which grow in wet places or in water, either partly or wholly submerged are called hydrophytes or aquatic plants. Examples are *Utricularia*, *Vallisneria*, *Hydrilla*, *Chara*, *Nitella*, Lotus, *Ceratophyllum*, *Trapa*, *Pistia*, *Eichhornia* (water hyacinth), *Wolffia*, *Lemna etc.* This group of plants probably originated from mesophytes. In the course of evolution several changes in the physiology, morphology and behaviour, all related to the aquatic mode of life, took place and by these evolutionary changes the mesophytic plants have become adapted to aquatic mode of life.

Classification of Hydrophytes

According to their relation to water and air, the hydrophytes are grouped into the following categories :

(a) Submerged hydrophytes

(b) Floating hydrophytes

(c) Amphibious hydrophytes

(*a*) **Submerged hydrophytes**. Plants which grow below the water surface and are not in contact with atmosphere are called submerged hydrophytes. Such plants are generally anchored to the bottom of the ponds, lakes, and other water sources. Examples—*Vallisneria*, *Hydrilla*, *Potamogeton*, *Najas*, *Ceratophyllum*, *Myriophyllum*, *Utricularia*, *Chara*, *Nitella* and a number of aquatic microbes.

(*b*) **Floating hydrophytes**. Plants that float on the surface or slightly below the surface of water are called floating hydrophytes. These plants are in contact with both water and air. They may or may not be rooted in the soil. On this ground the floating plants have been divided into two groups.

(*i*) **Free floating hydrophytes**. These plants float freely on the surface of water but or not rooted in the mud. Examples—*Wolffia arhiza* and *Wolffia microscopica* (a rootless minutest duck weed). *Trapa bispinosa*, *Lymnanthemum*, *Eichhornia crassipes* (water hyacinth, verna.—Jalkumbhi), *Salvinia* (a fern), *Azolla* (a water fern).

(*ii*) **Floating but rooted hydrophytes**. Some submerged plants are rooted in muddy substrata of ponds, rivers and lakes but their leaves and flowering shoots float on or above the surface of water. They are grouped as floating but rooted hydrophytes. Examples—*Nymphaea*, *Nelumbium speciosum* (Lotus), *Victoria regia* (water lily), *Ceratopteris thalictroides* (a hydrophytic fern of family Parkariaceae) etc.

(*c*) **Amphibious hydrophytes**. These plants are adapted to both aquatic and terrestrial modes of life. Amphibious plants grow either in shallow water or on the muddy substratum. Amphibious plants which grow in marshy places are termed as 'halophytes'.

Roots and some parts of stems and leaves in these plants may be submerged in water or buried in mud but some foliage, branches and flowering shoots spring well above the surface of water or they may spread over the land. The aerial parts of these amphibious plants show mesophytic or sometimes xerophytic features, while the submerged parts develop true hydrophytic characters. Some varieties of rice plants (*Oryza sativa*), *Scirpus*, *Marsilea*, *Sagittaria*, *Alisma*, *Jussiaea*, *Neptunia*, *Commelina*, *Polygonum*, *Typha*, *Ranunculus aquatilis*, *Phragmites*, *Enhydra fluctuans etc.* are familiar examples of this group of hydrophytes.

Factors affecting the plants in the Aquatic Environment

These are listed below :

1. Temperature of water
2. Osmotic concentration of water
3. Toxicity of water

The osmotic concentration and toxicity are dependent upon the amount and nature of chemical substances that are dissolved in water. The physiology of aquatic plants is greately affected by the change of osmotic concentration of water. The aquatic plants are subjected to less extremes of temperature because water is bad conductor of heat (*i.e.*, it takes long time in its heating and cooling). Hydrophytes are less affected as far as the transpiration from the plant tissue is completely out of question.

Hydrophytic Adaptations

As the aquatic environment is uniform throughout, the hydrophytes develop very few adaptive features. Important features of these plants are described in the following heads :

(a) Morphological

(*i*) **Roots**. Root systems in hydrophytes are poorly developed which may or may not be branched in submerged hydrophytes. Roots are meaningless as the entire surface of the plant body which is in direct contact with water acts as absorptive surface and absorbs water and minerals. This may probably be the reason why roots in hydrophytes are reduced or absent. Roots of floating hydrophytes show very poor development of root hairs. Roots in floating plants do not possess true root caps but very often they develop root pockets or root sheaths which protect their tips from injuries (Fig, 7.1). Exact functions of these root pockets, however, are not fully understood. Some rooted hydrophytes like *Hydrilla* (Fig. 7.2), *Vallisneria spiralis*, *Elodia canadensis*, though they derive their nourishments from water by their body surfaces, are partly dependent on their roots for minerals from the soil. Roots are totally absent in some plants, *e.g.*, *Ceratophyllum*, *Salvinia*, *Azolla*, *Utricularia etc.* In *Jussiaea repens* two types of roots develop when the plants are growing on the surface of water, some of them are normal while others are floating roots which are negatively

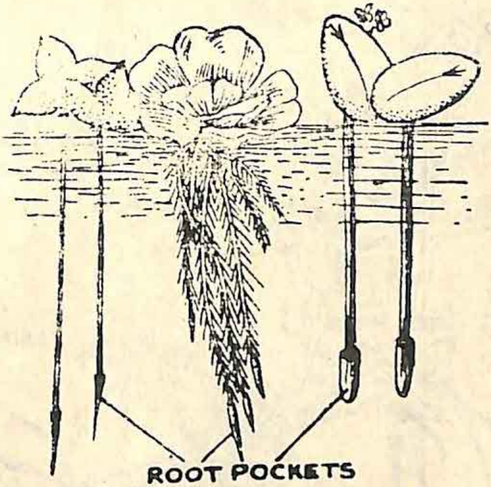


Fig. 7.1. *Pistia* and *Lemna* showing root pockets.

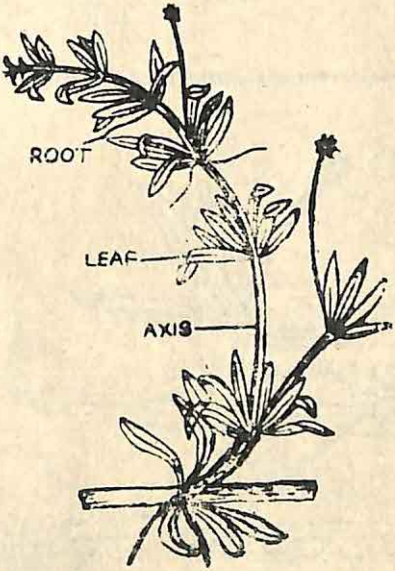


Fig. 7.2. *Hydrilla* plant with thin leaves and poorly developed roots.

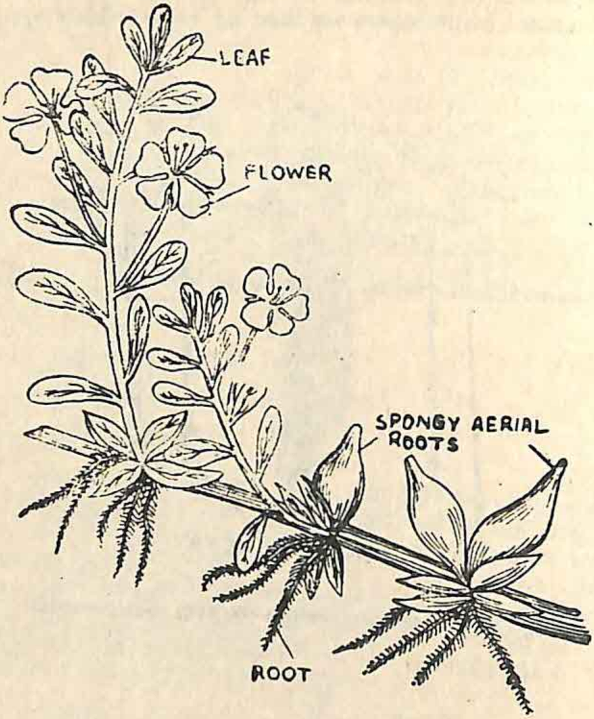


Fig. 7.3. ***Jussiaea repens*** **showing spongy respiratory roots.**

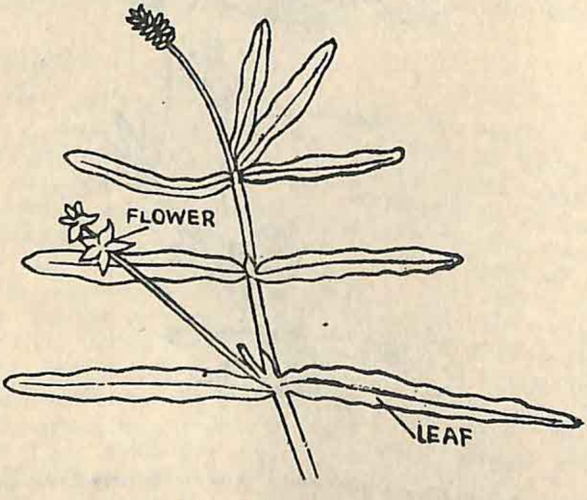


Fig. 7.4. ***Potamogeton.***

geotropic having spongy structures (Fig. 7.3). The floating roots help the plants keep afloat.

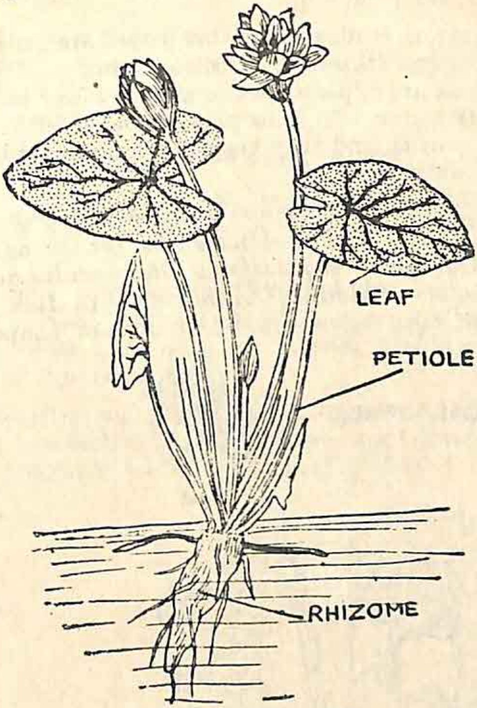


Fig. 7.5 Water lily.

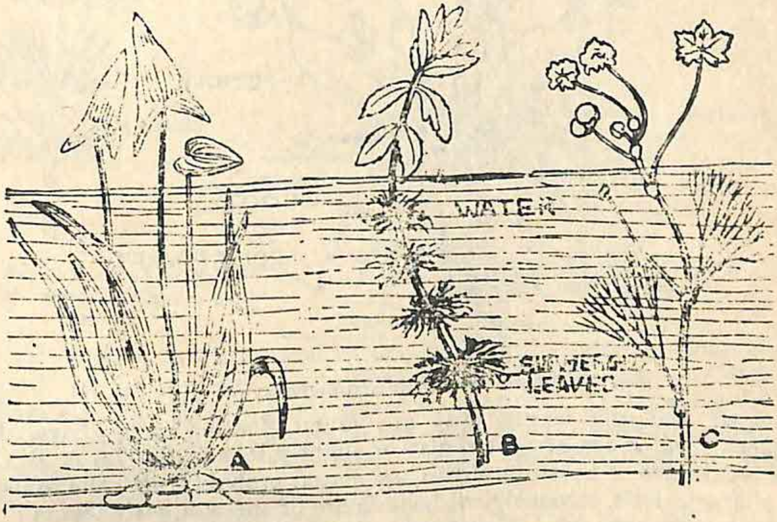


Fig. 7.6. A, B, C—Heterophylly
A—*Sagittaria*, B—*Limnophila heterophylla*,
C—*Ranunculus aquatilis*

(*ii*) **Stem**. In aquatic plants, it is very delicate and green or yellow in colour (Fig. 7.4). In some cases it may be modified into rhizome or runner, *etc.* (Fig. 7.5).

(*iii*) **Leaves**. (*a*) In floating plants leaves are generally peltate, long, circular, light or dark green in colour, thin and very smooth. Their upper surfaces are exposed in the air but lower ones are generally in touch with water. In lotus plant petioles of leaves show indefinite power of growth and they keep the laminae of leaves always on the surface of water.

(*b*) **Heterophylly**—Some aquatic plants develop two different types of leaves in them. This phenomenon is termed as heterophylly. Examples are *Sagittaria sagittaefolia*, *Ranunculus aquatilis*, *Limnophila heterophylla*, *Salvinia*, *Azolla etc.* In this phenomenon, generally the submerged leaves are linear ribbon shaped or highly dissected and the leaves that are found floating on or above the surface of water are broad circular or slightly lobed (Fig. 7.6 A, B, C). The occurrence of heterophylly is associated probably with the following characteristic physiological behaviours of these aquatic plants :

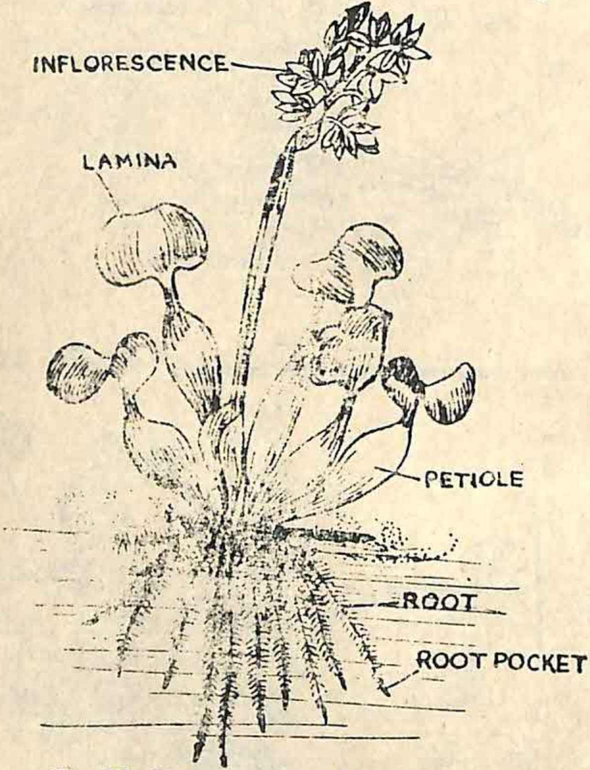


Fig. 7.7. Water hyacinth (*Eichhornia*)

(1) Quantitative reduction in transpiration.

(2) The broad leaves on the surface overshadow the submerged dissected leaves of the same plant and thus they

reduce the intensity of light falling on the submerged leaves. The submerged leaves require light to very low intensity.

(3) Plants show very little response to drought because the necessity of excess water during drought period is compensated by submerged leaves which act as water absorbing organs.

(4) Variation in the life-forms and habitats.

(5) Broad leaves found on the surface of water transpire actively and regulate the hydrostatic pressure in the plant body.

(*c*) Leaves of free floating hydrophytes are smooth shining and frequently coated with wax. The wax coating protects the leaves from chemical and physical injuries and also prevents the water clogging of stomata.

(*d*) In floating plants of water hyacinth, *Trapa etc.* the petioles become characteristically swollen and develop spongyness which provides buoyancy to these plants (Fig. 7·7).

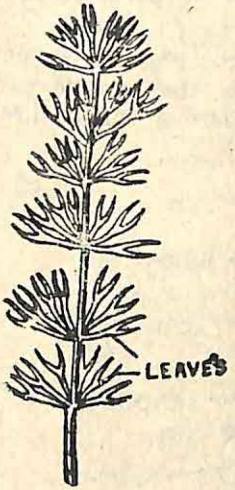


Fig. 7·8—*Ceratophyllum* showing highly dissected leaves.

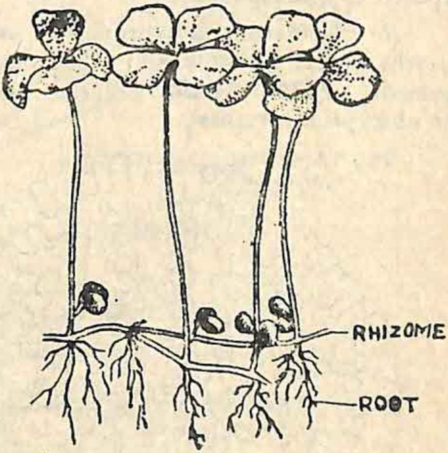


Fig. 7·9—*Marsilea* with creeping rhizome (Amphibious)

(*e*) Leaves in submerged hydrophytes are generally small and narrow. In some cases, *e.g.*, *Myriophyllum*, *Utricularia*, *Ceratophyllum etc.* they may be finely dissected (Fig. 7·8). The small slender terete segments of the dissected leaves offer little resistance against the water currents. In this way, plants are subjected to little mechanical stress and strains of water.

(*f*) In the Amphibious plants, the leaves that are exposed to air show typical mesophytic features (Fig. 7·9). They are more tough than the leaves of other groups of hydrophytes.

(*iv*) Pollination and dispersal of fruits and seeds are accomplished by the agency of water. Seeds and fruits are light in weight and thus they can easily float on the surface of water.

(*v*) Vegetative reproduction is common method of propagation in hydrophytes. It is accomplished either through fragmentation of ordinary shoots or by winter buds. In algae, reproduction is accomplished by zoospores and other specialized motile or non-motile spores.

(B) Anatomical modifications.

The anatomical modifications in hydrophytes aim mainly at—

(1) Reduction in protecting structures ;
(2) Increase in the aeration ;
(3) Reduction of supporting or mechanical tissues ;
(4) Reduction of vascular tissues.

Various anatomical adaptations of hydrophytes are listed below.

1. **Reduction in protecting structures**. (*a*) Cuticle is totally absent in the submerged parts of the plants. It may be present in the form of very fine film on the surfaces of parts which are exposed to atmosphere.

(*b*) Epidermis in hydrophytes is not a protecting layer but it absorbs water, minerals, and gases directly from the aquatic environment. Extremely thin cellulose walls of epidermal cells facilitate the absorption process.

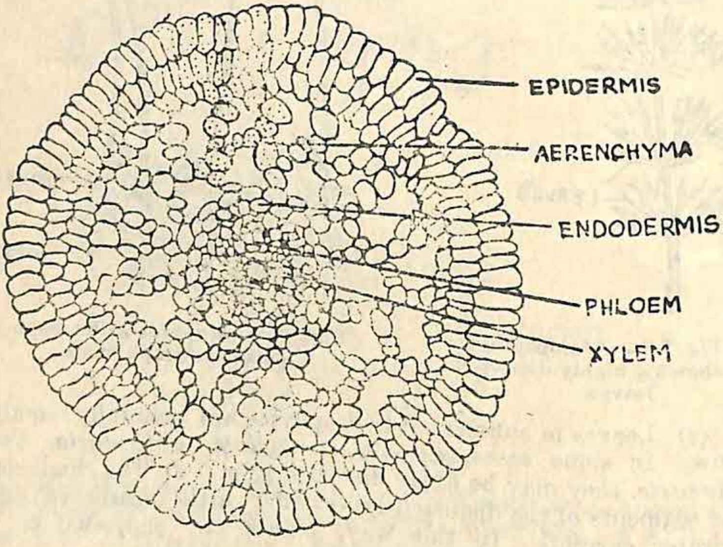


Fig. 7·10—T.S. of *Hydrilla* stem

(*c*) Epidermal cells contain chloroplasts, thus they can function as photosynthetic tissue, especially where the leaves and stems are very thin, *e.g. Hydrilla* (Fig. 7·10).

(*d*) Hypodermis in hydrophytes is poorly developed. Its cells are extremely thin walled.

2. **Increase in the aeration.** (*a*) Stomata are totally absent in submerged parts of the plants (Fig. 7·11 A,B and Fig. 7·12 B & E). In some exceptional cases, vestigial and functionless stomata have been noticed. In these cases exchange of gases takes place directly through cell walls. In the floating leaves, stomata develop in very limited number and are confined only to the upper surface (Fig. 7·13). In amphibious plants stomata may be scattered on all the aerial parts and they develop comparatively in larger number per unit area than those in the floating leaves (Fig. 7·14).

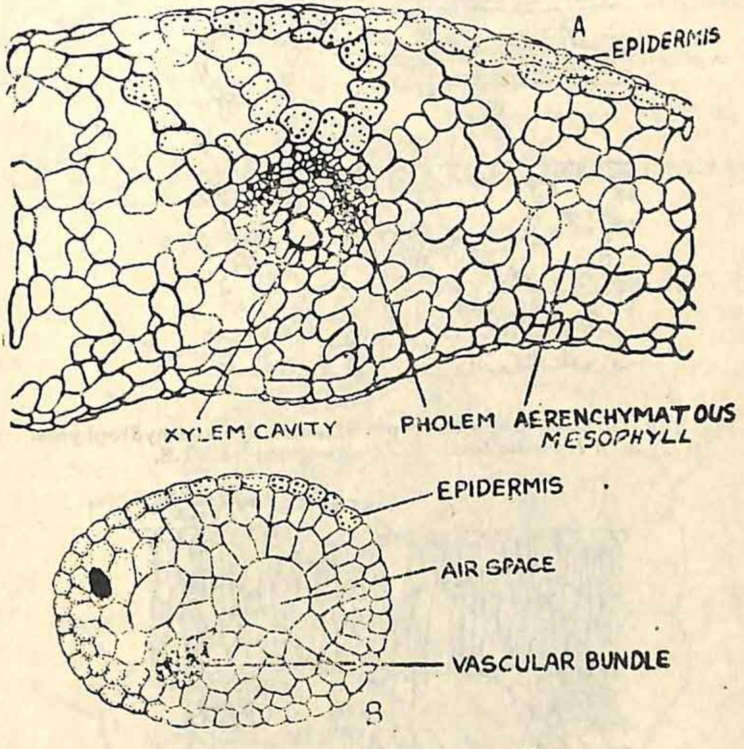


Fig. 7·11 A, B—T.S. of submerged leaves
(A) *Vallisneria*
(B) *Ceratophyllum*

(*b*) *Air chambers.* Aerenchyma in submerged leaves and stem is very much developed. Air chambers are filled with respiratory and other gases and moisture. These cavities are separated from one another by one or two cells thick chlorenchymatous partitions. The different types of air chambers are shown in Fig. 7·12 A, C, D. CO_2 present in the air chambers is used up in the photosynthesis and the O_2 produced in the process of photosynthesis and also that already present in the air chambers is used up in respiration. The air chambers also develop finely perforated cross septa which are called diaphragms (Fig. 7·15). These diaphragms afford better aeration and perhaps check flooding. The aerenchyma provides buoyancy and

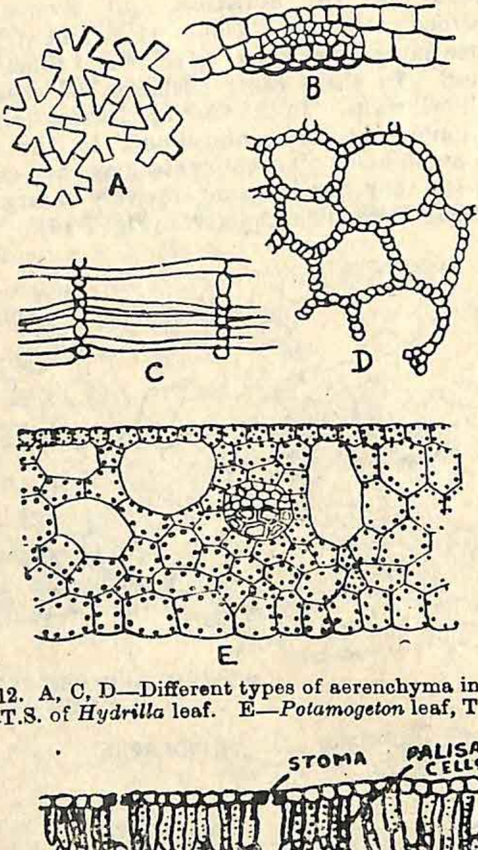


Fig. 7·12. A, C, D—Different types of aerenchyma in hydrophytes. B—T.S. of *Hydrilla* leaf. E—*Potamogeton* leaf, T.S.

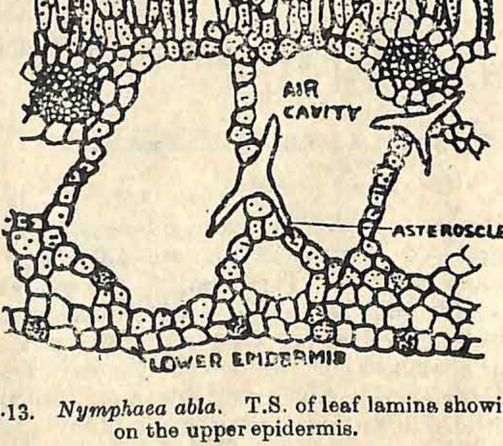


Fig. 7·13. *Nymphaea abla*. T.S. of leaf lamina showing stomata on the upper epidermis.

mechanical support to aquatic plants. Air chambers are abundantly found in the fruits of hydrophytes rendering them buoyant and thus facilitating their dispersal by water.

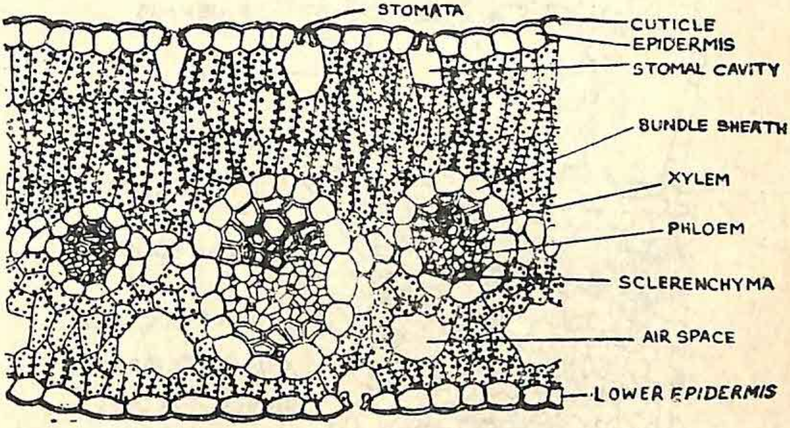


Fig. 7·14 V.S. of an amphibious leaf.

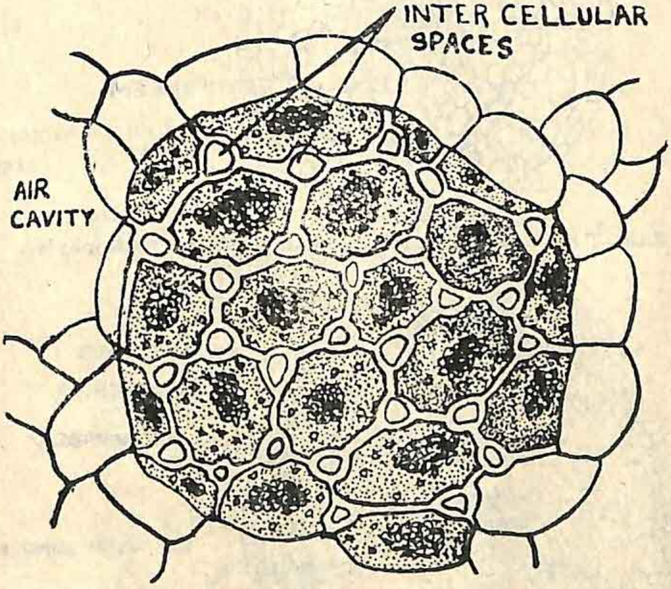


Fig. 7.15. A perforated septum (diaphragm) of an air chamber of *Eichhornia*.

Development of air chambers in the plants is governed by habitat. This point is clear from the anatomy of *Jussiaea suffructicosa*. In this case, air chambers develop normally if plants are growing in water but they seldom develop if the plants are growing on the land.

3. **Reduction of supporting or mechanical tissues.** (*a*) Mechanical tissue is absent or poorly developed in the floating and submerged parts of the plants because buoyant nature of water saves

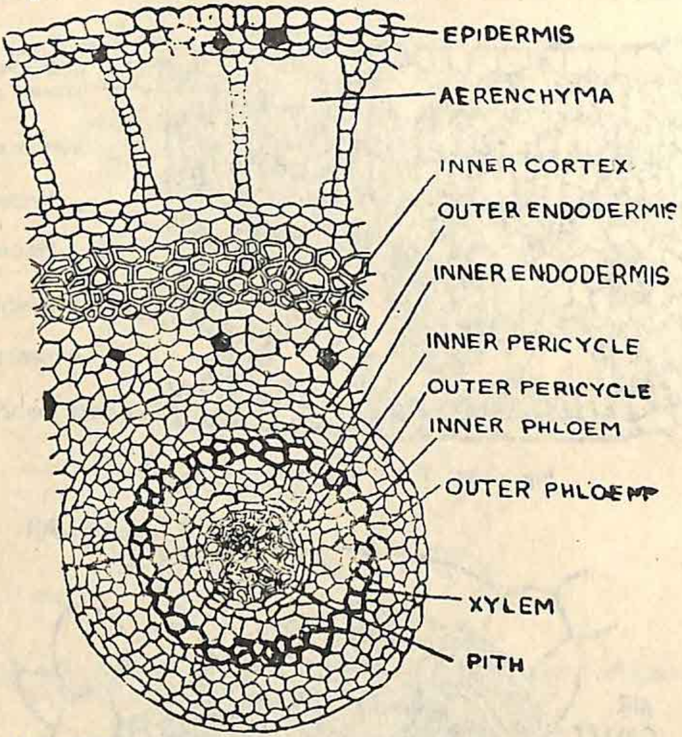


Fig. 7.16—T.S. of *Marsilea* rhizome (An amphibius hydrophyte).

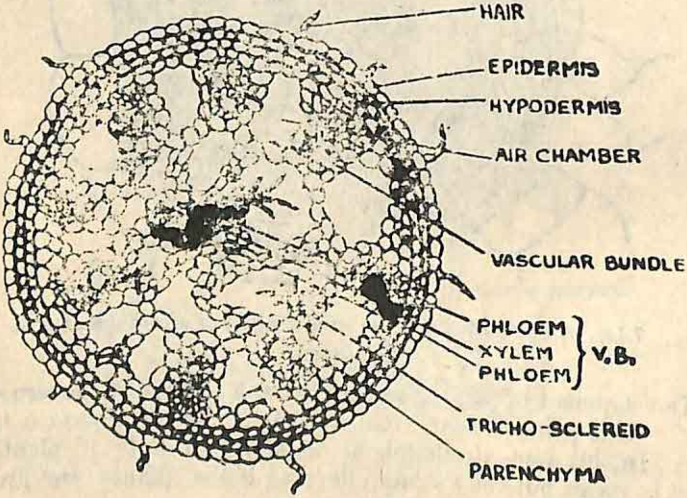


Fig. 7.17—T.S. of Petiole of *Nymphaea*

them from physical injuries. The thick walled sclerenchymatous tissue is totally absent in these plants. They may, however, develop in the cortex of amphibious plants, particularly in the aerial or terrestrial parts (Fig. 7.16). Generally elongated and loosely arranged spongy cells are found in the plant body. These thin-walled cells, when turgid, provide mechanical support to the plants.

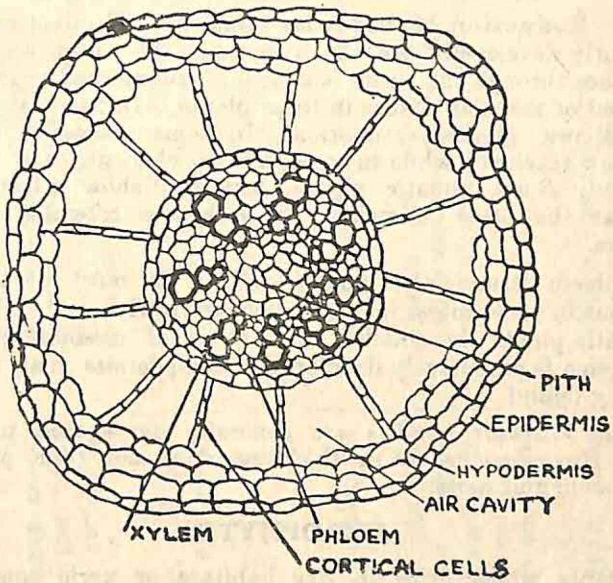


Fig 7.18.—T. S. of stem of *Jussiaea*

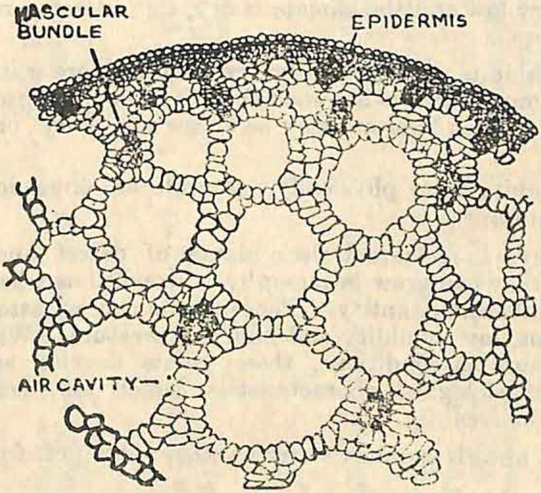


Fig. 7·19—T.S. of petiole of Eichhornia

(*b*) In water lily and some other plants, special type of star shaped lignified cells, called asterosclereids, develop which give mechanical support to the plants (Fig. 7.17).

4. **Reduction of vascular tissues.** Conducting tissue is very poorly developed. As the absorption of water and nutrients takes place through the entire surface of submerged parts, there is little need of vascular tissues in these plants. In the vascular tissues, xylem shows greatest reduction. In some cases, it consists of only a few tracheids while in some, xylem elements are not at all developed. Some aquatic plants, however, show a lacuna in the centre at the place of xylem. Such spaces resemble typical air chambers.

Phloem tissue is also poorly defined in most of the aquatic plants but in some cases it may develop fairly well. Sieve tubes of aquatic plants are smaller than those of mesophytes. Phloem parenchyma is extensively developed. *Endodermis* may or may not be clearly defind.

The *Vascular bundles* are generally aggregated towards the centre. *Secondary growth* in thickness does not take place in the aquatic stem and roots.

XEROPHYTES

Plants which grow in dry habitats or xeric conditions are called xerophytes. Places where available water is not present in adequate quantity are termed xeric habitats. Xeric habitats may be of following types :

(1) Habitats physically dry (where water retaining capacity of the soil is very low and the climate is dry, *e.g.*, desert, rock surface, waste land, etc.).

(2) Habitats physiologically dry (places where water is present in excess amount but it is not such that it can be absorbed by the plants easily. Such habitats may be either too salty or too acidic or too cold).

(3) Habitats dry physically, as well as physiologically, *e.g.*, slopes of mountains.

Xerophytes are characteristic plants of desert and semidesert regions, yet they can grow in mesophytic conditions where available water is in sufficient quantity. These plants can withstand extreme dry conditions, low humidity and high temperature. When growing under unfavourable conditions, these plants develop special structural and physiological characteristics which aim mainly at the following objectives :

(1) to absorb as much water as they can get from the surroundings ;

(2) to retain water in their organs for very long time ;

(3) to reduce the transpiration to minimum ; and

(4) to check high consumption of water.

Distinctive features of different groups of hydrophytes are summarised in the following chart :

Submerged plants	*Floating plants*	*Amphibious plants*
1. Entire surface of plant body remains in direct contact with water.	1. Some parts of the plants are in contact with water and some float on or above the surface of water.	1. Some parts of the plant body grow in water while some others above the surface of water or even on the land.
2. Leaves take CO_2 and oxygen from water.	2. These plants take CO_2 and oxygen partly from air and partly from water.	2. Generally the leaves absorb CO_2 and oxygen from the air because they are well exposed and exchange of gases can take place very easily through stomata.
3. Heterophylly is not so common.	3. Heterophylly may develop in these plants.	3. Heterophylly is very common.
4. Leaves are greatly reduced in size. They may be ribbon shaped, thin and sometimes very finely dissected.	4. Submerged leaves in the floating plants are thin, ribbon shaped entire or dissected but those floating on the surface of water are well expanded and entire.	4. Leaves are large, entire, tough and laminae or leaflets are found much above the surface of water.
5. Cuticle, suberin and epidermal hairs are not at all developed. Epidermis acts as absorptive surface rather than a protecting layer. A thin layer of mucilage may be present on the surface.	5. Surface of plant body is coated with a thin film of wax which protects the plant tissue from injurious effects of water and it also prevents clogging of stomata.	5. Cuticle develops on the aerial parts of the plants.

6. Stomata are absent or rarely present in very reduced stage.	6. Stomata are confined only to the upper surface of floating leaves.	6. Stomata are confined to both the upper and lower surfaces of the aerial leaves.
7. Mesophyll tissue is in the form of aerenchyma enclosing large air chambers. Palisade and spongy parenchyma are not very well differentiated.	7. Palisade cells are less developed and spongy tissue is aerenchyma.	7. Mesophyll shows clear differentiation into spongy and palisade tissues. Spongy parenchyma is very well developed with large air passages and diaphragms.
8. Stems are very slender and much reduced. They creep on the substratum either in the form of rhizomes or runners. The stem shows poorly developed vascular bundles. Aerenchyma is very well developed and air chambers are separated by cross septa or diaphragms.	8. Stem is well developed and the fibrovascular system is very much reduced, aerenchyma develops in abundance and air chambers are quite large.	8. Stem is extensively developed but in some, it may be reduced to rhizome. It shows clear differentiation of epidermis, cortex and stelar or vascular zones. Cortex in some cases is differentiated into distinct zones. Outer cortex is aerenchymatous enclosing a number of big air spaces. Inner cortex and pith may be formed of thick walled cells.
9. Roots in submerged plants are greatly reduced, unbranched and without root hairs. They act simply as anchorage organs. The root system shows poor internal organisation.	9. In some, root is absent while in others, it may be fully developed. Root hairs in free floating plants lie at right angles to the axis of main root. Some roots may be modified into floats, *e.g.*, in *Jussiaea*. Roots show poor differentiation of internal tissues. It functions as absorbing as well as anchoring organ.	9. Roots in amphibious plants are well developed. They show proper differentiation of all internal tissues. Root hairs develop on the epidermis,

Xerophytes are categorised into several groups according to their drought resisting power. These groups are as follows :

1. **Drought escaping plants**. These xerophytes are short-lived. During critical dry periods, they survive in the form of seeds and fruits which have hard and resistant seedcoats and pericarps respectively. At the advent of favourable condition (which is of very short duration), the seeds germinate into new small sized plants which complete their life cycles within a few weeks time. The seeds become mature before the dry condition approaches. In this way plants remain unaffected by extreme conditions. These are called *ephemerals*. These plants are very common in the semiarid zones where rainy season is of short duration. Examples—*Astragalus* (Papilionatae), some inconspicuous compositae (*e.g.*, *Artemesia*) and members of families Zygophyllaceae, Boraginaceae and some grasses etc.

2. **Drought enduring plants.** These are small sized plants which have capacity to endure or tolerate drought.

3. **Drought resistant plants**. These plants develop certain adaptive features in them through which they can resist extreme droughts.

Xerophytes grow on a variety of habitats. Some grow on rocky soil (Lithophytes), some in deserts, some on the sand and gravels (Psammophytes) and some may grow on the waste lands (Eremophytes). Some plants of xeric habitat have water storing fishy organs, while some do not develop such structures. On this ground xerophytes can be divided into two groups which are as follows :

(1) Succulent xerophytes,

(2) Non-succulents, also called true xerophytes.

Succulent xerophytes are those plants in which some organs become swollen and fleshy due to active accumulation of water in them or in other words, the bulk of the plant body is composed of water storing tissue. Water stored in these tissues is consumed up during the period of extreme drought when the soil becomes depleted of available water

Xerophytic Adaptations

Plants growing in the dry habitats develop certain structural devices in them. These structural modifications in xerophytic plants may be of two types.

(*i*) **Xeromorphic characters**. Xerophytic characters that are genetically fixed and inherited are referred to as xeromorphic. They will appear in the xerophytes irrespective of conditions whether they are growing in desert or in humid regions. Halophytic mangroves and many other evergreen trees, although growing in most conditions always develop xeromorphic characters.

(*ii*) **Xeroplastic characters**. These features are induced by droughts and are always associated with dry conditions. They are never inherited. These characters may disappear from plants if all the favourable conditions are made available to them. Important xerophytic features are summarised under the following heads :

(1) Morphological (external) adaptations :

(2) Anatomical (or internal) adaptations ;

(3) Physiological adaptations.

1. External Morphology of Xerophytes

(A) **Roots**. Xerophytes have well developed root systems which may be profusely branched. It is extensive and more elaborate than shoot system. Many desert plants develop superficial root system where the supply of water is restricted to surface layer of the earth. The roots of perennial xerophytes grow very deep in the earth and reach to the layers where water is available in plenty. Root hairs are densely developed near the growing tips of the rootlets. These enable the roots to absorb sufficient quantity of water.

(**B**) **Stem** Some of the important characteristics of xerophytic stems are listed below :

(*i*) Stems of some xerophytes become very hard and woody. It may be either aerial or subterranean.

(*ii*) They are covered with thick coating of wax and silica (as in *Equisetum*). Some may be covered with dense hairs as in *Calotropis*.

(*iii*) In some xerophytes, stems may be modified into thorns, *e.g.*, *Duranta*, *Ulex* etc. (Fig. 7·20).

(*iv*) In stem succulents, main stem itself becomes bulbous and fleshy and it seems as if leaves in these plants are arising directly from the top of the roots. Example—*Kleinia articulata.*

(*v*) Stems in some extreme xerophytes are modified into leaf like flattened, green and fleshy structures which are termed as phylloclades. Many cacti (Fig. 7·21) and cocoloba (*Muehlenbeckia*) are familiar examples for this (Fig. 7·22A). In *Ruscus* plants, the branches developing in the axils of scaly leaves become metamorphosed into leaf like structures, the phylloclades or cladophylls (Fig. 7·22 B). In *Asparagus* plant (Fig. 7·22 C) also a number of axillary branches become modified into small needle-like green structures which look exactly like leaves. They are called Cladodes. A number of species of *Euphorbia* also develop succulence and become green. In these plants, leaves are greatly reduced, so the main function of leaves, the photosynthesis, is taken up by these green phylloclades or cladodes which are modified stems,

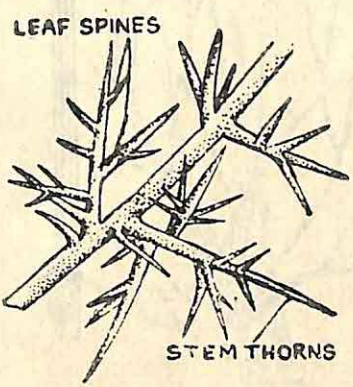


Fig. 7·20—*Ulex* Stem

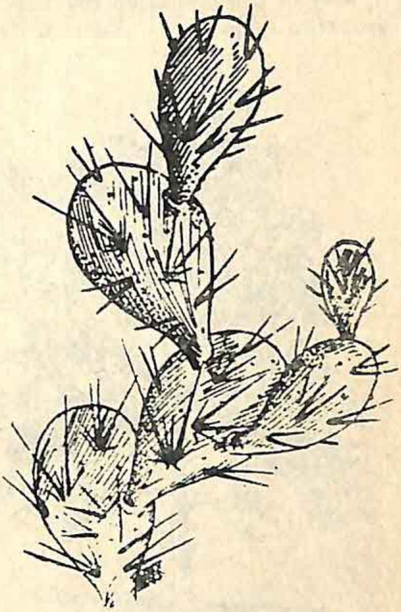


Fig. 7·21—*Opuntia*

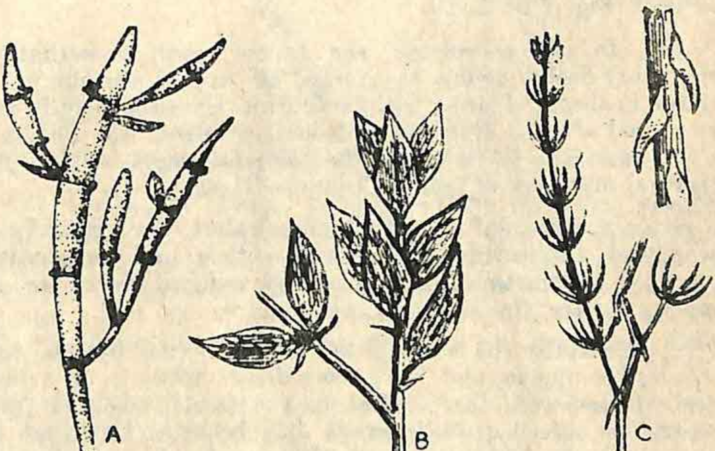


Fig. 7·22 A, B & C—Phylloclade and cladodes
A—Phylloclade of Cocoloba.
B—Cladodes of *Ruscus*.
C—Cladodes of *Asparagus*.

(C) Leaves (*i*) In some xerophytes the leaves, if present, are greatly caducous, *i.e.*, they fall early in the season, but in the majority of the plants leaves are generally reduced to scales, as in *Casuarina* (Fig. 7·23), *Ruscus*, *Asparagus*. (Fig. 7·22 B, C) etc.

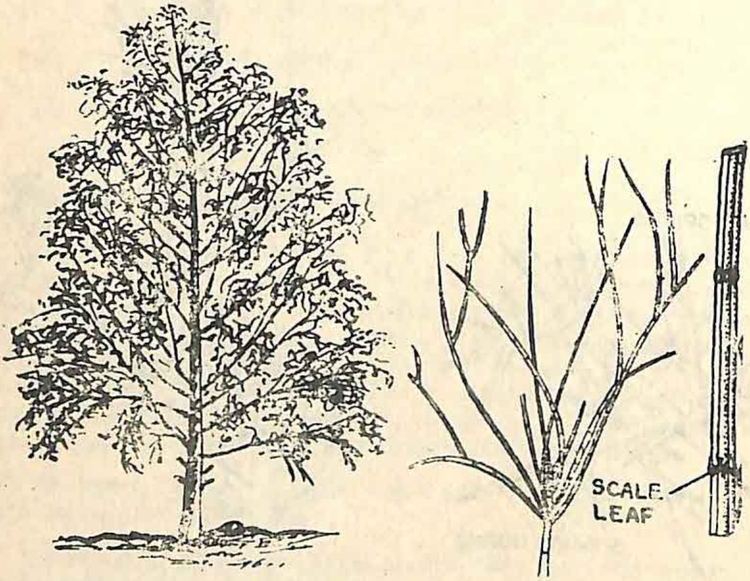


Fig. 7·23 – *Casuarina*.

(*ii*) Some evergreen xerophytes have needle shaped leaves, *e.g.*, *Pinus* (Fig. 7·24 A. B).

(*iii*) In leaf succulents, the leaves swell remarkably and become very fleshy owing to storage of excess amount of water and latex in them. Plants with succulent leaves generally develop very reduced stems. Examples of leaf succulents are *Sedum acre*, *Aloe spinossissima* (Gheekwar), *Mesembryanthemum*, *Kleinia ficoides* and several members of family Chaenopodiaceae.

(*iv*) In majority of xerophytes, leaves are generally much reduced and are provided with thick cuticle and dense coating of wax or silica. Sometimes they may be reduced to spines, as for examples, in *Ulex*, *Opuntia* (a cactus).

(*v*) Generally the leaves of xerophytic species possess reduced leaf blades or pinnae and have very dense network of veins. In Australian species of *Acacia* (Babool) the pinnae are shed from the rachis and the green petiole swells and becomes flattened taking the shape of leaf. This modified petiole is termed as phyllode (Fig. 7·25). The phyllode greatly reduces the water loss, stores excess amount of water and performs photosynthesis.

(*vi*) *Trichophylly*. In some xerophytes especially those growing in the regions exposed to strong wind, the under surfaces of the leaves are covered with thick hairs which protect the stomatal guard cells and also check the transpiration. Those xerophytes which have hairy covering on the leaves and stems are known as *trichophyllous plants*. *Nerium*, *Calotropis procera* are important examples.

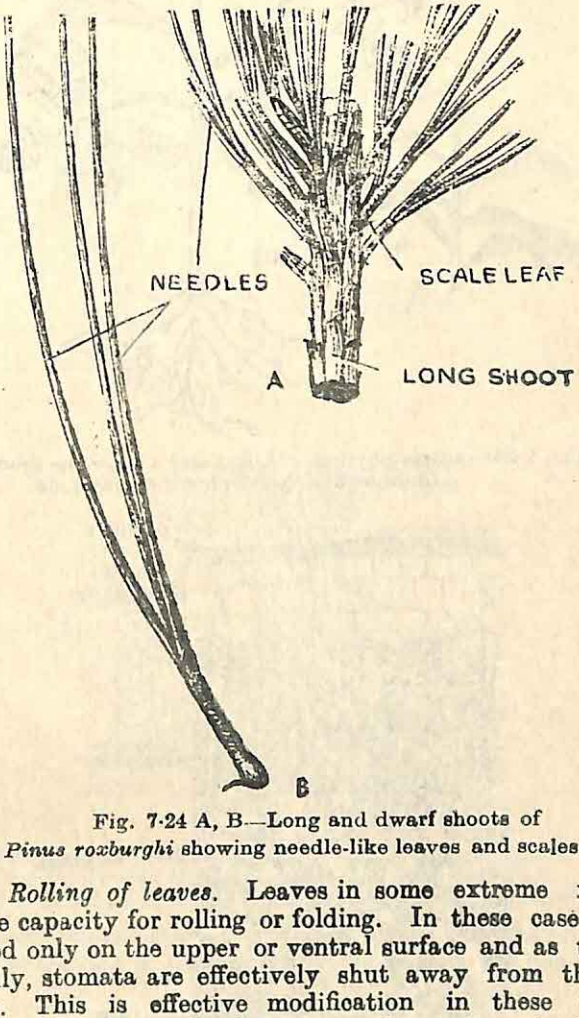


Fig. 7·24 A, B—Long and dwarf shoots of *Pinus roxburghi* showing needle-like leaves and scales.

(*vii*) *Rolling of leaves.* Leaves in some extreme xerophytic grasses have capacity for rolling or folding. In these cases stomata are scattered only on the upper or ventral surface and as the leaves roll upwardly, stomata are effectively shut away from the outside atmosphere. This is effective modification in these plants for reducing the water loss. Sundune grass is an important example for this.

(D) **Flowers, fruits and seeds.** Flowers usually develop in the favourable conditions. Fruits and seeds are protected by very hard shells or coatings.

2. Anatomical modifications in the xerophytes.

A number of modifications develop internally in the xeric plants and all aim principally towards water economy. The following are the anatomical peculiarities met within xerophytes :

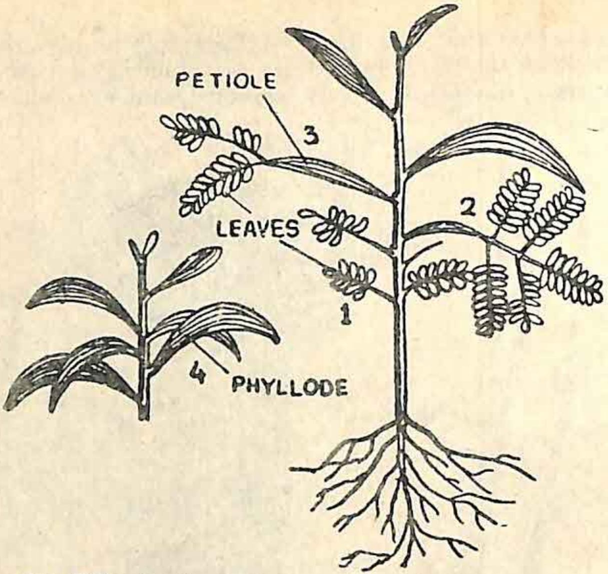


Fig. 7·25—*Acacia* phyllode. 1, 2, 3 and 4 show the gradual loss of pinnae and development of phyllode.

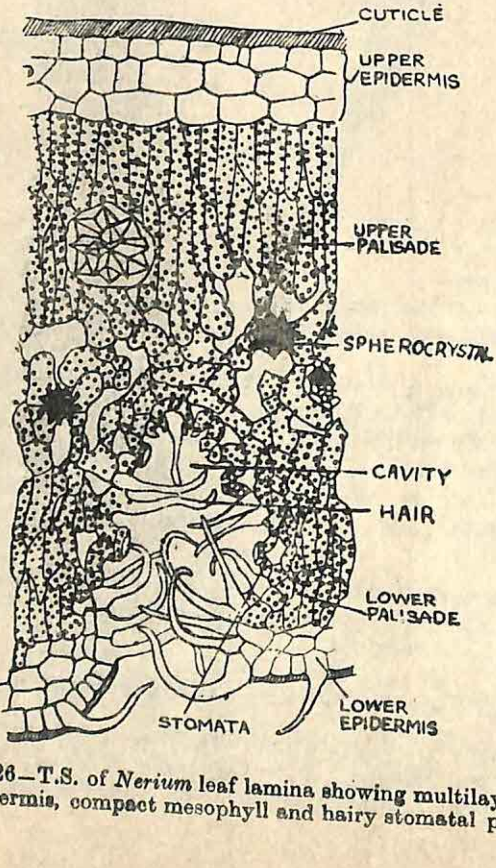


Fig. 7·26—T.S. of *Nerium* leaf lamina showing multilayered epidermis, compact mesophyll and hairy stomatal pit.

(*i*) Heavy cutinisation, lignification and wax deposition on the surface of epidermis and even in the hypodermis are very common in xerophytes. Some plants secrete wax in small quantity but some are regular source of commercial wax. Shining smooth surface of cuticle reflects the rays of light and does not allow them to go deep into the plant tissues. Thus, it checks the heavy loss of water.

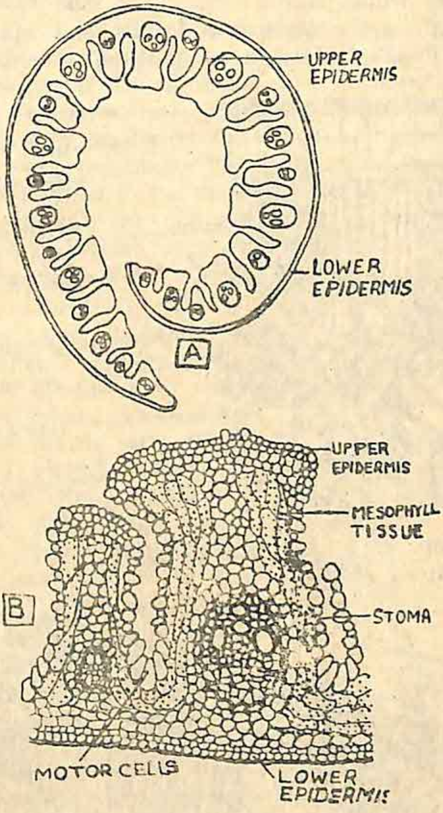


Fig. 7·27 A—T.S. of upwardly rolled leaf of *Psamma* grass
B—A part of rolled leaf section in detail showing motor cells or bulliform cells and stomata on the upper epidermis.

(*ii*) **Epidermis**. Cells are small and compact. It is single layered, but multiple epidermis is not uncommon. In *Nerium* leaf, epidermis is two or three layered (Fig. 7.26). In stems, the epider. mal cells are radially elongated. Wax, tannin resin, cellolose etc. deposited on the surface of epidermis form screen against high intensity of light. This further reduces the evaporation of water from the surface of plant body. Certain grasses with rolling leaves have specialized epidermis (Fig. 7·27 A & B). In these, some of the epidermal cells that are found in the depressions become more enlarged than those found in the ridges. These enlarged cells are thin walled and are called bulliform cells or motor cells or hinge cells. These are found usually on the upper surface of leaves between two parallel running vascular bundles. The highly specialized motor cells facilitate the rolling of leaves by becoming flaccid during dry periods In moist conditions these cells regain their normal turgidity which causes unrolling of the leaf margins. Bulliform cells are of common occurrence in the leaf epidermis of sugarcane, bamboo, *Typha* and a number of other grasses.

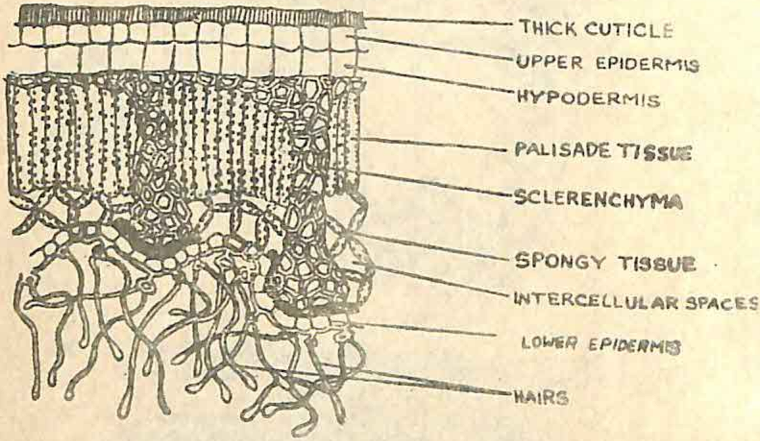


Fig. 7·28—V. S. of *Banksia* leaf

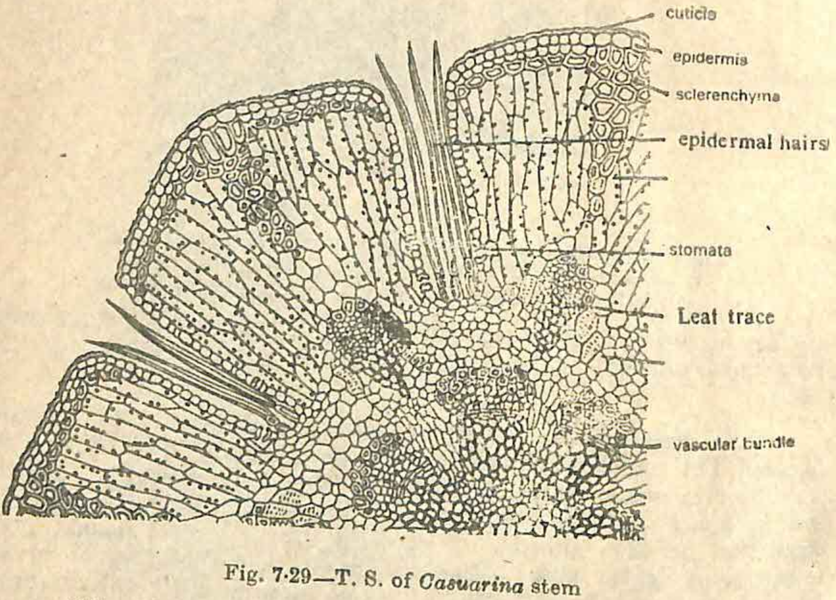


Fig. 7·29—T. S. of *Casuarina* stem

(iii) **Hairs.** Hairs are epidermal in origin. They may be simple or compound, uni-or multicellular. Compound hairs are branched at the nodes. These hairs protect the stomata and prevent excessive water loss. In some plants, surfaces of stems and

leaves develop characteristic ridges and furrows or pits. The furrows and pits in these plants are the common sites of stomata. Hairs found in these depressions protect the stomata from the direct stroke of strong wind (Fig. 7·28, 7·29).

(*iv*) **Stomata**. In xerophytes, reduction of transpiration is of utmost importance. It is possible only if the stomatal number per unit area is reduced or if the stomata are elaborately modified in their structures. In xerophytes, number of stomata per unit area of leaf is greater than in mesophytes. They are generally of sunken type. In some cases, they may be found in the furrows or pits. Subsidiary cells of sunken stoma may be of such shapes and arrangement that they form an outer chamber that is connected by narrow opening of the stoma. Such type of specialised stomata are very common in conifers (Fig. 7·30), *Cycas*, *Equisetum*, *etc.* Walls of the guard cells and subsidiary cells are heavily cutinised and lignified in many xeric plants. These devices have little value in directly reducing transpiration when stomata are open. When the plants are wilting and stomata are closed then only lignified or cuticularized walls of guard cells have protecting properties and under such circumstances only cuticular transpiration is possible which is of little significance. In dorsiventral leaves stomata are generally found on the lower surface, but in rolling leaves they are scattered mostly on the upper surface. In the rolled leaves, stomata are protected from the direct contact of outside wind. This is very important rather secured device for lowering the rate of transpiration in xerophytic grasses.

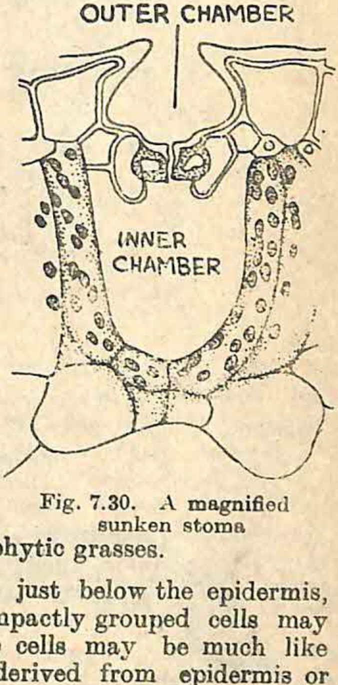


Fig. 7.30. A magnified sunken stoma

(*v*) **Hypodermis**. In xerophytes, just below the epidermis, one or several layers of thick walled compactly grouped cells may develop that form the hypodermis. The cells may be much like those of epidermis and may either be derived from epidermis or from the cortex (in case of stem) or from the mesophyll (in case of leaf). The hypodermal cells may sometimes be filled with tannin and mucilage.

(*vi*) **Ground tissue**. (*a*) In the stem, a great part of body is formed by sclerenchyma. In those cases where the leaves are either greatly reduced or they fall in the early season, the photosynthetic activity is taken up by outer chlorenchymatous cortex (Fig. 7·31). The chlorenchymatous tissue is connected with the outside atmosphere through stomata. The gaseous exchange takes place in regular manner in the green part of stem.

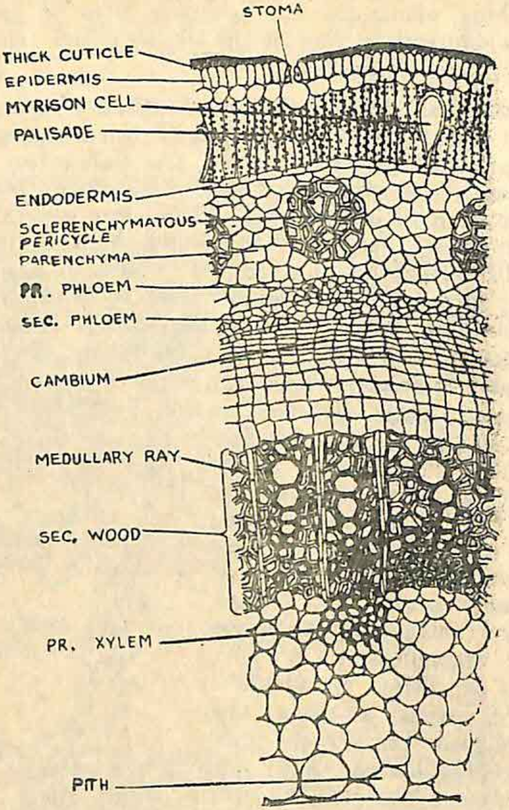


Fig. 7·31—T.S. of *Capparis* stem.

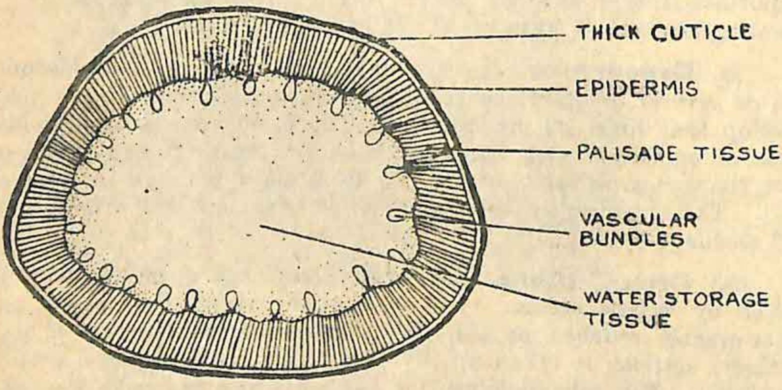


Fig. 7·32A—T.S. of a succulent leaf of *Aloe*.

(*b*) In succulent stems and leaves, ground tissue area is filled with thin walled-parenchymatous tissue which stores excess quantity of water, mucilage, latex etc. This makes the stems swollen and fleshy (Fig. 7·32 A & B).

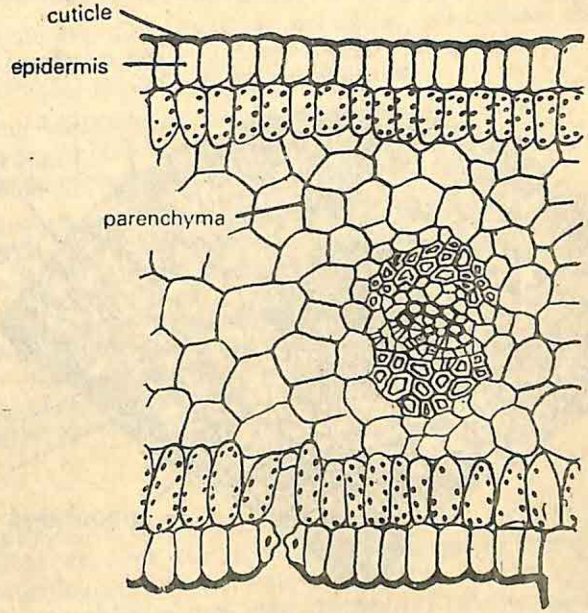


Fig. 7·32 B—T.S. of *Agave* leaf showing water storing parenchyma.

(*c*) In the leaves, mesophyll is very compact and the intercellular spaces are greatly reduced. Palisade tissue develops in several layers. There are some xerophytes in which mesophyll is surrounded by thick hypodermal sheath of sclerenchyma from all the sides except from below. This sheath forms a diaphragm against intense light. Such xerophytes in which sclerenchyma is extensively developed are called sclerophyllous plants. In succulent leaves, spongy parenchyma develops extensively which stores water. In *Pinus*, the spongy cells of mesophylls are star shaped (Fig. 7·33).

(*d*) Intercellular spaces are greatly reduced. Cells in the body are generally very small, thick walled and compactly grouped. They may be spherical, rounded or cuboid in shape. Such cells are very common in xerophytes.

(*vii*) **Conducting tissues** Conducting tissues, *i.e.*, xylem and pholem, develop very well in the xerophytic body.

3. Physiological adaptations

It was long assumed that the structural adaptations in the body of xerophytes were useful in reducing the transpiration but now a number of experiments related with the physiology of these plants reveal some facts which are contrary to the early assumptions.

Works of Maximov support that except succulents, true xerophytes show very high rate of transpiration. Under similar conditions, the rate of transpiration per unit area in xerophytes is much higher than that of mesophyte. Stomatal frequency per unit area of leaf surface in xerophytes is also greater than that in the mesophytic leaf.

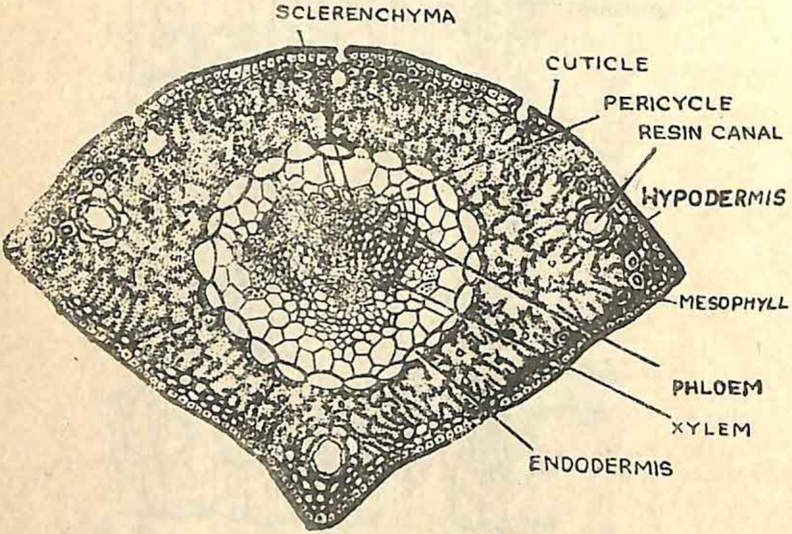


Fig. 7·33—T.S. of *Pinus* needle.

(1) Succulents are well known to contain polysaccharides, pentosans and a number of acids by virtue of which they are able to resist the drought. The structural modifications in these succulent xerophytes are directly governed by their physiology. How does the succulence develop ? Metabolic reaction which induces development of succulence is the conversion of polysaccharides into pentosans. Pentosans have water binding property. These pentosans together with nitrogenous compounds of the cytoplasm cause accumulations of excess amount of water in the cells and consequently the succulence develops.

(2) Another experimented fact in the physiology of succulent plants is that their stomata open during night hours and remain closed in day. This unusual feature is associated with metabolic activity of these plants. In dark, these plants respire and produce acids. The heavy accumulation of acids in the guard cells increases osmotic concentration which, in turn, causes inward flow of water in the guard cells. When guard cells become turgid the stomata open. In the sunlight, acids dissociate to produce carbon dioxide which is used up in the photosynthesis and as a result of this osmotic concentration of cell sap decreases which ultimately causes closure of stomata.

(3) In xerophytes, the chemical compounds of cell sap are actively converted into wall forming compounds that are finally incorporated into the cell walls. Conversion of polysaccharides into anhydrous forms, such as cellulose, formation of suberin etc., are some examples.

(4) Some enzymes such as catalases, peroxidases, are more active in xerophytes than in mesophytes. In xerophytes, amylase enzyme hydrolyses the starch very actively.

(5) The capacity of xerophytes to survive in long periods of drought lies not only in the structural features but also in the resistances of the hardened protoplasm to heat and desiccation.

(6) **Regulation of transpiration**. Presence of the cuticle, polished surface, compact cells and sunken stomata protected by stomatal hairs regulate the transpiration.

(7) **High osmotic pressure of cell sap**. The xerophytes have very high osmotic pressure which increases the turgidity. The turgidity of cell sap exerts tension of force on the cell walls. In this way, wilting of cell is prevented. High osmotic pressure of cell sap also affects the absorption of water.

MESOPHYTES

Mesophytes are common land plants which grow in situations that are neither too wet nor too dry. These plants cannot grow in water or water-logged soils nor can they survive in dry places. In other words, mesophytes are the plants of those regions where climates and soils are favourable. Vegetations of forests, meadows and cultivated fields belong to this category. The simplest mesophytic community comprises the grasses and herbs, richer communities have herbs and bushes and richest ones have trees (rain forest in tropics).

Mesophytes can be classified into two main community groups :

(1) Communities of grasses and herbs.

(2) Communities of woody plants.

1. Communities of grasses and herbs

These include annual or perennial grasses and herbs. The grasslands occur in area of approximately 10″ to 30″ rain fall per annum. They occur over large interior areas in many countries of the world as U.S.A., Canada, Australia, Argentina, Southern Russia, Africa, India. The different types of grasslands and herb communities are listed below.

(*i*) **Arctic and alpine mat grasslands and mat herbage** : Such communities are restricted to polar regions and mountain tops. The plants are small sized soft shrubs, and the under shrubs are totally absent. Mosses may be intermingled but lichens do not appear. This group is subdivided into two :

(*a*) Mat grassland (Gramineae)

(*b*) Mat herbage (Dicotyledonous herbs such as *Saxifraga*, *Delphinium*, *Potentilla*, *Ranunculus*, etc.)

(*ii*) **Meadow**. This forms a connecting link between mesophytes and hydrophytes as they grow in soils where moisture is 60—83%. Plants are tall perennial herbs with long stems. Soil is invisible due to overcrowding of plants. Plants are mostly rhizomatous. The leaves show mesophytic features, *i.e.*, they are thin, broad, flat and glabrous. Members of families Gramineae, Ranunculaceae, Papilionatae and Compositae are found in abundance.

(*iii*) **Pasture on culitvated land**. Vegetation is shorter and more open than in meadow. It is disturbed very often by grazing. The vegetation usually includes grasses, dicot herbs and some mosses.

2. **Communities of woody plants (Bushland and forests)**

These are classified and described in the following ways :

(*i*) **Mesophytic bushlands**. Such a mesophytic community occurs where temperature and other conditions are not favourable for the growth of forests but they are too much favourable for mat herbage vegetation. In many places, xerophytic and mesophytic bushlands merge with each other. *Salix*, *Arabis*, *Lathyrus*, *Vicea*, etc., are the important plants of bushlands.

(*ii*) **Deciduous forests**. These forests are found in the areas where rainfall is high enough (about 30″—60″ per year) and evenly distributed and the temperature is moderate. Such forests are characterised by trees which become leafless for certain periods of the year. The foliage persists for about five to eight months. This phenomenon of repeated foliation and defoliation of trees is prominent in temperate and cold regions (where there is long winter) and in tropics as well where the summer is of long duration. Leaves are dorsiventral and they exhibit many shapes and structures. The trees are profusely branched. Mycorrhizae are present in the roots. Epiphytic mosses and lichens grow in abundance on the surfaces of the trees. The majority of the plants are pollinated by wind. The soil is very rich in microflora. The deciduous forests are named after dominant trees of those particular communities, as for example, *Quercus-Oak* forest, *Betula-Birch* forest, *Fagus-Beach* forest and so on.

Tropophytes (changing plants), an interesting group of tropical plants, can be included in this group of mesophytes. Generally in tropical regions, the climate remains more or less uniform throughout the year but in some tropics there is alternation between damp and dry cold climates. Plants growing in the tropics of disuniform climates develop some structural modifications through which they can endure the regular cycle of favourable and unfavourable seasons in one way or in other. In other words, tropophytes behave as xerophytes during rainy season. The shedding of leaves may occur in the beginning of winter season or in the summer. Important adaptive features of these plants are :

(*a*) better protection of winter buds

(*b*) thick bark covering on the stem

(*c*) formation of underground stem which protects the perennating buds from extreme drought and cold. Conifers are the familiar examples of tropophytes.

(*iii*) **Evergreen forests.** These forests are found in the tropical and subtropical regions extending into the cold temperate zones of southern hemisphere. Plants in these forests are evergreen (*i.e.*, they retain their leaves for more than one year until new foliage appears). Very few species in these forests may show leaffall. Evergreen forests are of three types :

(*a*) **Antarctic forests.** These forests cover mountains of New Zealand and a number of other countries in the world where annual temperature ranges from 5°C to 70°C and the rainfall is abundant throughout the year. Important plants found in these forests are conifers, Myrtaceae, Hymenophyllaceae. Mosses and Liverworts may also be present.

(*b*) **Subtropical forests.** These forests are found in the regions of fairly high rainfall but where temperature differences between winter and summer are less marked. Winter generally goes without rains. The plants are about 30 metres in height. These forests include *Oaks*, *Magnolias*, *Tamarindus* and mosses. Subtropical forests occur in Eastern part of U.S.A., South Brazil, South Africa, East Australia, Southern China, and Japan.

(*c*) **Tropical Rain forests or Tropical Evergreen forests.** Tropical rain forests are found in low lying regions near the equator with annual rainfall of 180 cm or more. This type of forests is most dense and is undisturbed by biotic agencies and is, therefore, called "primeval forest". The rain forests represent the climax vegetation of the whole world. Climate of such a forest is characterized by—

(1) high humidity (air saturated by 95% humidity)

(2) high temperature

(3) daily rains

(4) no distinct dry season

(5) soil very rich in humus, black in colour, and porous.

The plants show luxuriant growth and they are found in several storeys. Humboldt very appropriately commented "forest is piled upon forest", *i.e.*, highest trees form top layer about 40—50 metres up, beneath which is found storey of short trees, then storey of low palms and trees, ferns then, storey of scattered herbs and shrubs (4 to 5 metres in height). On the surface of ground may be found *Selaginella*, mosses etc. (Fig. 7·32).

Roots of the plants may be found covered by saprophytes and parasites, *e.g.*, *Rafflesia*, *Balanophora*, *Monotrapa* etc. Epiphytes and lianas are very common in these forests. Very dense growth of the shrubs and climbers makes the forests impenetrable. Plants usually acquire tree forms. Most of them produce root buttresses for the support of their huge trunks. They show cauliflory in which the buds are protected by stipules, leaf sheaths and petioles etc. Flowers are of various colours and they develop high over the heads. Plants do not show periodicity for foliation and flowering. Each species has its own flowering and foliation time. The leaves exhibit almost all shapes and are usually directed upwardly to drain off excess water. The leaf surface is cutinised and impregnated with silica which protects them from violent rains. Leaves may be provided with channelled nerves and dripped tips (*i.e.*, they have long and narrow apices). Trees develop thick barks.

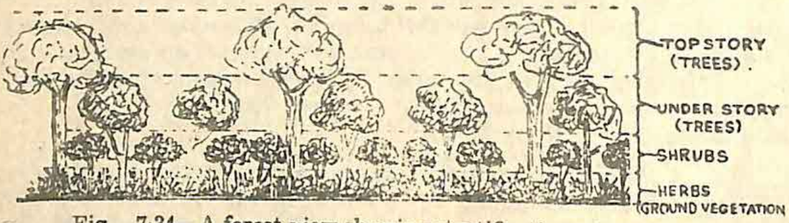


Fig. 7·34—A forest view showing stratification of the plants

Plants belonging to families Leguminoceae, Lauraceae, Myrtaceae, Moraceae etc. are very commonly found in tropical rain forests.

Vegetational succession in the tropical rain forest takes place in the following sequence :

The pioneer colonisers are deciduous plants that are replaced gradually by semideciduous vegetation that persists for very short period of time after which semi-evergreen plants will make their appearance. The semi-evergreen vegetation becomes intermingled with some evergreen plants which finely becomes dominant. In this way the climax forests develop. This sequence is possible only if the biotic factors are not allowed to affect the vegetation to a major degree. Tropical rain forests are found in central and southern America, central Africa, Pacific Islands, Malaya and in many other equatorial countries of the world. In India, these forests are found in south-eastern Himalayas, tracts of Assam, and western slopes of Nilgiri.

The tropical rain forests are of great economic values to the human beings. These yield timbers of high quality.

QUESTIONS

1. What are hydrophytes ? Describe the various morphological and anatomical adaptations met within hydrophytes.

2. Describe the various features of different groups of hydrophytes. Illustrate your answer with suitable examples.

3. What are xerophytes ? Describe the various morphological and physiological adaptations of xerophytes.

4. Describe the main ecological adaptation of plants growing in water ponds.

5. Write short notes on following :

Succulents, Amphibious plants, Heterophylly, Sclerophylly, Bulliform cells, Trichophylly, Diaphragm.

8

EPIPHYTES

(*Epi*=above, *phyton*=plant. *i.e.*, plant growing upon plant)

Epiphytes are those autotrophic plants which grow on the surface of some other supporting plants and are not permanently rooted in the soil. Orchids, Bo tree (Pipal tree), some algae, lichens and mosses are some of the familiar examples. These plants absorb sufficient moisture from the atmosphere and mineral nutrients from the decaying bark of the supporting plants upon which they are situated. As they are autotrophic in nutrition, they manufacture their own food (carbohydrates) from water and CO_2 in presence of sunlight. These plants differ from parasites because they do not derive nutrients and water from the living parts of supporting plants, and also they differ from lianes (woody stem climbers) because epiphytes, in the real sense of the term, are not permanently rooted in the soil. Epiphytes are also called *Aerophytes* or air plants.

Distribution

Some epiphytes grow on the surface of submerged aquatic plants, while others may be aerial. Some are found growing on the surface of tree trunks, some on the horizontal forks of the trees and some may grow even on the surface of leaves (*i.e.*, epiphyllous epiphytes). Some epiphytes show specificity in selection of their supporting plants. *Tortula pagorum*, an epiphytic moss, is peculiar in the sense that it grows on the tree trunks within the urban limits. This moss grows well in the city atmosphere presumably because it requires high temperature and smoky air for its normal growth. Both these factors are available to the plants in the city area. Some epiphytic species may often grow on rocks, and some may grow rarely even on the poles and horizontal telephone wires.

Epiphytic vegetation is very rich in moist and cold regions but poor in dry and cold areas. In north-western Himalayas the epiphytic species are much less in number in comparison to those present in the eastern Himalayas. In warm and wet regions, members of the families Bromeliaceae and Orchidaceae are found in abundance. In tropical rain forests, epiphytic species found at the tops of trees are xerophytic in nature but those occurring at lower levels are hygrophilous (moisture and shade loving).

Important Features

Since the epiphytes depend directly for their water supply on rains, atmospheric moisture, snow and dew, they develop certain structural adaptations for water storage and for reducing excessive water loss. The important features are listed below :

1. Morphological Features

(i) **Root System** In the epiphytic vascular plants, the root system is extensively developed. In these cases, the roots may be of the following three types (Fig. 8·1) :

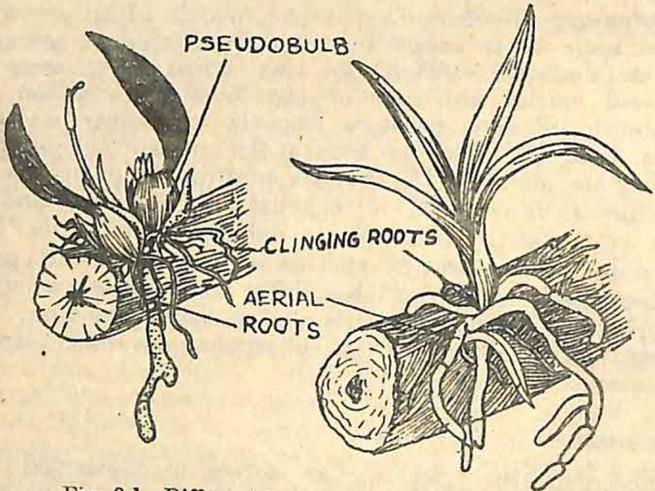


Fig. 8·1—Different types of roots in epiphytes.

(a) **Normal Absorbing Roots**. Which absorb water, minerals, and organic nutrients from the moist crevices of decaying barks of supporting plants.

(b) **Clinging Roots**. These roots fix the epiphytes on the surface of the supporting object firmly and also absorb nutrients from the humus and dust that are accumulated on the surface of the bark.

(c) **Aerial Roots**. These are spongy and green roots which hang downwardly in the atmosphere and absorb moistnre from the air. These roots can photosynthesize in light because of the presence of green colour in them.

In some epiphytes, the roots collect on their surface good amount of dust that holds water which will finally be absorbed by the roots.

(ii) **Stem.** Stem in epiphytic vascular plants may or may not be extensively developed. Some epiphytes develop succulence in their stems and become pseudobulbous or tuberous (Fig. 8·1).

(iii) **Leaves.** The majority of epiphytes show considerable reduction in leaf number. Some orchids develop only a single leaf in a growing season. Leaves in some may be fleshy and leathery. In *Dischidia nummularia*, *Platycerium* and *Asplenium nidus* leaves are modified into the pitchers.

Dischidia nummularia, an epiphytic species of family Asclepiadaceae, growing very commonly in Sunderban shows peculiar type of leaf pitchers. The pitchers have openings through which the adventitious roots enter inside. The roots branch copiously into a number of very delicate rootlets which spread on the entire inner surface of pitcher and form a network (Fig. 8·2). The inner surface of pitcher is coated with wax. Pitcher collects and accumulates rain water, humus and minerals that are absorbed by the root network. Sometimes ants and insects enter the cavity of the pitcher through hole where they may be killed and digested. The dead remains of animals serve as nitrogen sources for the plants. Myrmecophily which is a sort of symbiotic association between ants and plants is of common occurrence in the epiphytic vegetation. In the family Bromeliaceae, some species develop spoon like leaves in rosettes. These leaves collect and store rain water which is finally absorbed by the epidermal hairs present on the concave surface of the leaves.

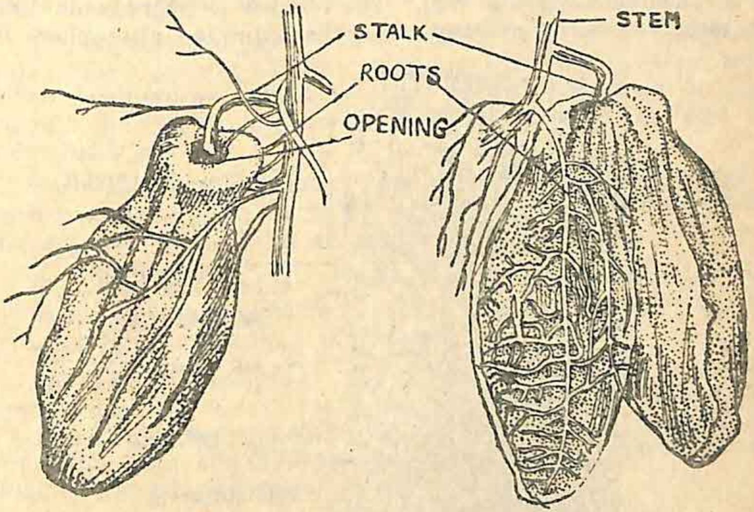


Fig. 8·2—Leaf pitchers of *Dischidia nummularia*. Right pitcher is cut open longitudinally to show network of roots on its inner surface.

(iv) **Fruits, Seeds and their dispersal**. The fruits and seeds are usually dispersed by wind, insects and birds. When the seeds reach the suitable surface and get favourable environment, they germinate over there and give rise to new independent epiphytes.

2. Anatomical Features

Important anatomical peculiarities in epiphytes are as follows :

(*i*) Presence of thick cuticle and sunken stomata : These two structures greatly reduce the loss of water from the plants. Generally the surface cells of water absorbing organs (roots and some leaves) are not cuticularized.

(*ii*) In succulent epiphytes, thin-walled parenchymatous tissue that stores water, develops extensively.

(*iii*) The aerial hanging roots of many tropical epiphytes belonging to the families Araceae and Orchidaceae develop on their surface a characteristic greenish white, thin-walled **massive** tissue that is called velamen (Fig. 8·3). The velamen is hygroscopic tissue that rapidly absorbs moisture from the saturated atmosphere like a sponge. It is modification of multilayered epidermis. Its cells are empty (*i.e.*, dead) and cell walls show spiral or reticulate thickenings. Inner to the velamen there is present a peculiar layer called '*exodermis*'. Exodermal cells are of two types :

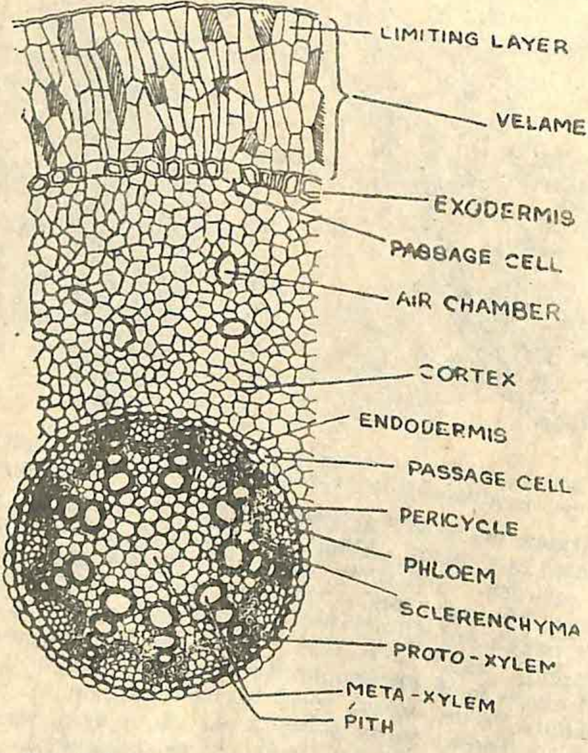


Fig. 8·3—T.S. of aerial root of orchid showing velamen.

(*a*) Lignified and thick-walled cells.

(*b*) Thin-walled cells or passage cells, walls of which are permeable to water. The velamen absorbs and retains moisture till that is absorbed by passage cells of exodermis.

(*iv*) Other structures are similar to those found in mesophytes.

Types of Epiphytes

Schimper has classified epiphytes into four subgroups which are as follows :

(1) **Protoepiphytes.** *These plants derive their nourishments* partly from the surface of the supporting plants and partly from the atmosphere. They do not develop any adaptive feature in them except, perhaps, aerial roots with velamen. Examples : *Peperomia, Dischidia* and some ferns belong to this group.

(2) **Hemiepiphytes.** These plants grow on the supporting plants in the beginning like true epiphytes but later on they establish connection with the soil by their roots. Epiphytic fig trees, some root climbing Aroids, *Scindapsus officinalis* etc. are important plants of this group.

Some stem climbing plants grow in the soil but their stems die from below upward and terminal portions live independently like hemiepiphytes. Such plants are termed as Pseudoepiphytes.

(3) **Nest epiphytes.** These plants have appropriate devices to collect large quantity of water and humus for their own use, orchids are familiar examples of this group.

(4) **Tank epiphytes.** These plants develop fibrous anchoring roots which do not take part in the water absorption. Leaves, that are variously modified, absorb water and manufacture food. *Nidularium, Tillandsia,* and other epiphytic species of Bromeliaceae are common plants of this group.

QUESTIONS

1. What are epiphytes ? Describe the various morphological features of epiphytes.

2. Write short noteson :

(*i*) Velamen (*ii*) Root system of epiphytes.

9

HALOPHYTES AND MANGROVE VEGETATION

Some plants grow and complete their life cycle in habitats with a high salt content. They are known as salt plants or halophytes. According to Stocker (1933) the critical level of salinity for plants is 0·5% of the dry weight. Though the fact that only a small group of higher plants can grow in the saline habitats was recognized many hundred years ago, yet the name "halophyte" was assigned to such plants by Pallas in the early nineteenth century. Such plants are commonly found near sea shores where mesophytes and fresh water hydrophytes can not thrive well. Although these plants grow in the areas which are well saturated with water yet they cannot avail of the water because of high concentration of salts in the soils. Thus, the halophytes are plants of physically wet but physiologically dry habitats. Plants cope with the problems of salinity in various ways, some of them avoid salinity, some evade salinity or resist it, and a few others tolerate salinity. Salinity avoidance is usually accomplished by limiting germination, growth and reproduction to specific seasons of the year as well as by growing roots into non-saline layers and limiting salt uptake. Plants evade or resist salinity by accumulating salts in their cells as well as by secretion of excess salts. In the salt tolerants, the protoplasm functions normally and endures a high salt concentration without apparent damage.

Plants occupying only local non-salty ecological niches in an overall saline environment or those which appear in such habitats only for short periods, *i.e.*, during rainy seasons are called pseudo-halophytes or false halophyte (Yoav Waisel, 1972). Saline habitats are not restricted to sea coasts only but they may also be found in many dry places far away from the sea coasts. In India, certain places in Rajasthan and in many other deserted places, the soils are very salty because of presence of sodium chloride, calcium sulphate, sodium bicarbonate, potassium chloride, etc. In these dry and salty habitats generally succulent xerophytes, *e.g.*, *Chaenopodium album*, *Suaeda fructicosa*, *Haloxylon salicorneum*, *Salsola foestida*, *Tamarix articulata* grow very successfully and form microedaphic formations.

Classification of Halophytes

Stocker (1933) proposed first classification of saline habitats which is as follows :

1. Aquatic-haline
2. Terrestro-haline
    - (*a*) hygrohaline
    - (*b*) mesohaline
    - (*c*) xerohaline
3. Aero-haline
    - (*a*) Habitats affected by salt spray (maritime)
    - (*b*) Habitats affected by salt dust (salt desert)

On the basis of contact between salt and plant in different habitats halophytes can be grouped into the following categories :

1. In terrestrial saline habitat, the contact occurs between the plant roots and soil—*terrestrial halophytes*.
2. In aquatic-haline habitat contact occurs :
    - (*a*) between salt and plant roots—*Emerged halophytes* or *hygrohalophytes*, and
    - (*b*) between salt and entire plant body — *Submerged halophytes* or *Hydrohalophytes*.
3. In aero-haline habitat, the contact occurs :
    - (*a*) between aerial organs of plants and air borne salt droplets (in coastal regions) or (*b*) between aerial organs and salt droplets (in dust deserts)—*Aerohalophytes*.

Iversen (1936) classified the habitats on the basis of their salt contents. Different habitats and plants found therein are given below :

	Habitat	*Salt content*	*Plants*
1.	Oligohaline	0·01—0·1% NaCl	Oligohalophytes
2.	Mesohaline	0·1 —1·0% NaCl	Mesohalophytes
3.	Polyhaline	1% NaCl and up	Euhalophytes

Besides above-mentioned three types of halophytes, there are some other halophytes which grow in habitats with wider salinity ranges. Plants occurring in both oligohaline and mesohaline habitats are called oligo-mesohalophytes and those existing in all the three types of habitats are called euryhalophytes.

According to Chapman (1942) halophytes have been classified into the following categories :

(*i*) **Miohalophtes**—Plants growing in the habitats of low salinity (below 0·5% NaCl).

(*ii*) **Euhalophytes**—Plants of high saline habitats. They have been further sub-divided into the following groups :

- (*a*) **Mesohalophytes**—Plants of habitats with salinity range of 0·5-1%.
- (*b*) **Mesoeuhalophytes**—Plants of habitats with salinity range of 5% or higher.
- (*c*) **Eneuhalophytes**—Plants of habitats with salinity range of 1% and up. Van Eijk (1939) classified halophytes into the following two main categories on the basis of their distribution and their responses to saline habitats.

(*i*) **Salt enduring halophytes** which show optimum development in non-saline habitats but can tolerate salts.

(*ii*) **Salt resistant halophytes** which show optimum development in saline habitats.

Tsopa (1939) classified halophytes in the following four groups on the basis of their response to salinity :

1. **Obligatory halophytes** — Plants requiring salinity throughout their life.

2. **Preferential halophytes**—Plants show optimum growth in saline habitats, despite their appearance in non-saline habitats.

3. **Supporting halophytes**—Nonaggressive plants which are capable of growing in saline habitats.

4. **Accidental halophytes**—Plants which grow in marsh saline habitats only accidentally. Steiner (1935) classified salt marsh plants in the following three types :

- (*a*) **Succulent halophytes**—Plants which can tolerate high concentration of chloride in their cell sap due to increase in succulence (as for example, *Salicornia herbacea*).
- (*b*) **Non-succulent halophytes**—Plants resisting salts by desalinization of their tissues and secreting excess salts through salt glands (*e..g.*, *Spartina alterniflora*).
- (*c*) **Accumulating types**—Plants without any special mechanism of salt removal. Salt concentration in such plants goes on increasing until the death of plants (*e.g.*, *Juncus gerardii*, *Suaeda fructicosa*).

Coastal angiospermous halophytes have been divided into the following groups :

(*i*) Submerged marine halophytes—*hydrohalophytes.*

(*ii*) Low coast plants—hygrohalophytes.

(*a*) *Swamp halophytes*, the **mangrove**.

(*b*) *Marsh halophytes*.

(*iii*) High coast plants—*aerohalophytes*.

Mangrove is a West Indian name given to formation of trees and shrubs inhabiting the coasts and river estuaries of tropical or subtropical seas. Plants occurring in mangrove vegetation belong to several families. Common mangrove plants are *Rhizophora mucronata*, *Kandelia rheedii*, *Ceriops roxburghiana*, *Bruguiera gymnorhiza* and many other plants belonging to the family Rhizophoraceae, *Avicennia officinalis* of the family verbinaceae, *Acanthus ilicifolius* (Acanthaceae), *Ardesia humiles* and *Aegiceras majus* of family Myrisinaceae, *Cassula species* (a very common plant of rice field in northern India belonging to the family compositae), *Cometes surathensis* (Caryophyllaceae) which is commonly found in western Asia, *Avicennia*, *Sechium edule* (Aroideae)—an Indomalayan plant, *Cryptaeorine ciliata* (Aroideae)—a common plant growing in the muddy banks of Ganga, *Poa*, *Festuca*, *Melacanna*, *and Oryza patnai (Rice) of family* Gramineae, *Scirpodendron* of Cyperaceae and a number of other plants belonging to the families Palmae, Parkeriaceae Chaenopodiaceae, Plumbaginaceae, Ficoideae, Euphorbiaceae.

Mangrove plants are very commonly found on some saline soils of Indogangetic plains (Bay of Bengal, Sunderbun and Assam), in western India near the sea coasts of Bombay and Kerala, in the banks of Gaumati and Godavari in south India, particularly in the regions where rivers meet the ocean, and in Andaman and Nicobar Islands.

Mangrove vegetation of Gangetic estuary, particularly of Sundarbun region, according to Prain, are localized in the following three georaphical zones :

(1) Southern coastal strip and south-western part

(2) Central zone

(3) North-eastern part

The Central zone is characterized by climax forest of *Heritiera*. *Ceriops* is one of the dominant plant species on the higher grounds near the sea and at certain places it may form pure forest in Sunderbun.

Mangrove vegetation in the western sea coast of India is represented by the following plant communities :

(*i*) *Avicennia alba* and *Avicennia officinalis* community,

(*ii*) *Acanthus ilicifolius* and *Avicennia alba* community,

(*iii*) *Suaeda fructicosa* population,

(*iv*) Pure community of *Salvadora* species,

(*v*) *Sesuvium portulacastrum* population, and

(*vi*) *Aeluropus repens* population.

Godavari delta in Andhra (South India) shows characteristic mangrove vegetation of *Avicennia alba, Avicennia marina, Rhizophora, Bruguiera, Ceriops, Sonneratia, Acanthus ilicifolius, Myriostachya weightiana, Clerodendron inerme*, etc.

The ecological conditions which are essential for development of mangrove vegetation or halophytes are :

(*a*) shallow water with thick mud,

(*b*) water logged saline soil or sandy or loose soil or heavy clays containing large amount of organic matter,

(*c*) high rainfall, and

(*d*) high humidity in the atmosphere and cloudy weather.

Important Characters of Halophytes

As the water in the habitat is not such that can easily be absorbed by the plants, the halophytes develop almost all important xerophytic devices in them for water economy.

1. **Habit.** A great majority of halophytes in the tropical and subtropical regions are shrubs, but a few of them are herbaceous, for example, *Acanthus ilicifolius*. In temperate zones, halophytic vegetation is purely herbaceous.

The shrubs are generally dome-shaped in appearance because of their cymose branching.

2. **External morphology.** (a) **Roots** (*i*) Halophytes develop many shallow normal roots. In halophytes, in addition to normal roots, many stilt or prop roots develop from the aerial branches of stem for efficient anchorage in muddy or loose sandy soil. These roots grow downwardly and enter the deep and tough strata of the soil. In some plants, *e.g., Rhizophora mucronata*, the stilt roots may be strong and extensively developed, but in others they may be poorly developed (*Rhizophora conjugata*). In some plants, the stilt roots may not at all develop.

(*ii*) Sometimes, a large number of adventitious root buttresses develop from the basal parts of tree trunks. These root buttresses provide sufficient support to the plants.

(*iii*) The soil in coastal region is poorly aerated and it contains very little percentage of oxygen because of water logging. Under such conditions, the roots of halophytes do not get sufficient aeration. In order to compensate this lack of soil aeration, the hydrohalophytes develop special type of negatively geotropic roots, called '*pneumatophores*' or breathing roots (Fig. 9·1). The pneumatophores usually develop from the underground roots and project in the air well above the surface of mud and water. They appear as peg-like structures. The tips of these respiratory roots may be pointed. They possess numerous lenticels or pneumathodes on their surface and prominent aerenchyma enclosing large air cavities internally. The gaseous exchange takes place in these roots through the lenticels.

The aerenchyma helps in the conduction of air down to the subterranean or submerged roots. In some plants, *e.g.* *Bruguiera*, the horizontal roots grow above the surface of mud and then again bend

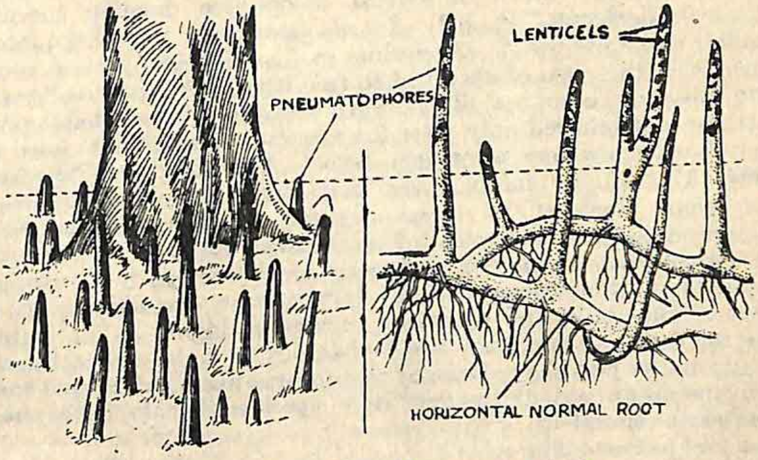


Fig. 9·1—Pneumatophores of mangrove plant.

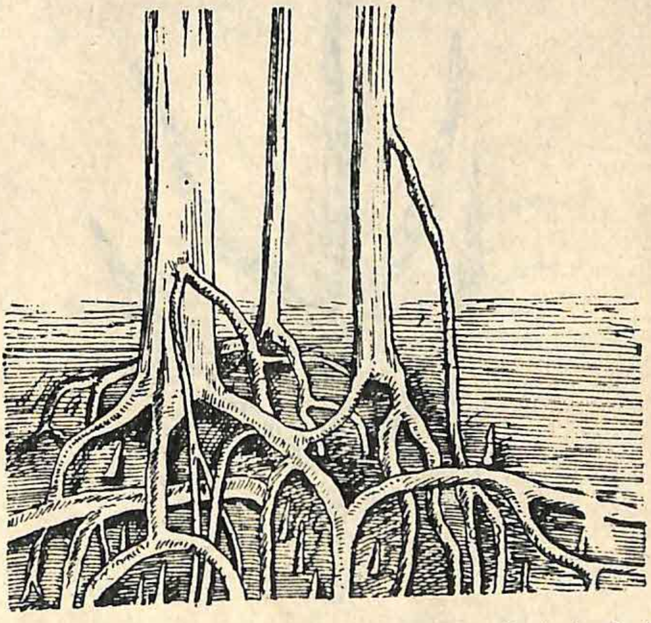


Fig. 9·2—Supporting or stilt roots of mangrove plants developing from the trunk.

downwardly and enter deep in the mud. In this way, they form knee-like structures. The aerial surface bears a number of pores which facilitate the exchange of gases (Fig. 9·2). Pneumatophores do not develop in some species of *Rhizophora*. In those cases, the upper aerial parts of descending stilt roots probably take up the respiratory activity.

(*b*) **Stem.** Stems in several halophytes develop succulence. *Salicornia herbacia* (Fig. 9·3), *Suaeda maritima* may be quoted as familiar examples for it. According to Arnold (1955), the succulence depends on the ratio of absorbed to free ions in the plant cells rather than absolute amounts of sodium, chloride, or sulphate present. Succulence is induced only after the accumulation of free ions in an organ increases above a critical level. According to Pokrovskaya (1954, 57) salinity inhibits the cell division and stimulates cell elongation. Such effects cause decrease in the cell number and increase in cell size, so typical of succulents. **Repp** *et al* (1959) are of the opinion that succulence is directly correlated with salt tolerance of plants and the degree of their development can serve as an indicator of the ability of plants to survive in highly saline habitats. The temperate halophytes are herbaceous, but the tropical ones are mostly bushy and show dense cymose branching. Submerged marine angiosperms are among the very few species of halophytes that do not become succulent.

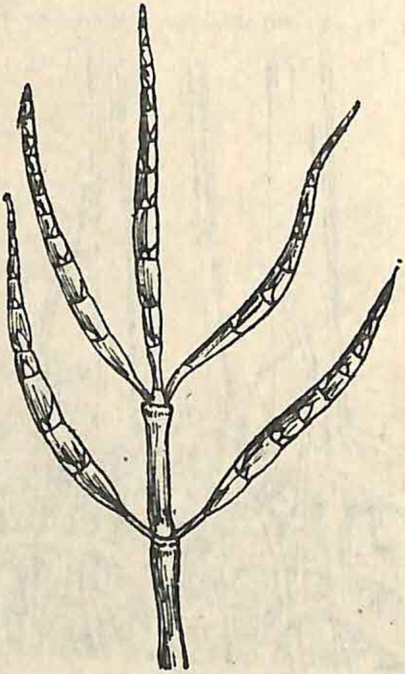


Fig. 9·3—*Salicornia herbacia*, a succulent halophyte.

(*c*) **Leaves.** The leaves in most of the halophytes are thick, entire, succulent, generally small sized, and are often glassy in appearance. Some species are aphyllous. Stems and leaves of coastal aerohalophytes show additional mode of adaptation to their habitats. Their surfaces are densely covered with trichomes.

Leaves of submerged marine halophytes are thin, and have very poorly developed vascular system and frequently green epidermis. They are adapted to absorb water and nutrients from the medium directly.

(*d*) **Fruits, Seeds and their dispersal.** The fruits and seeds are generally light in weight. Fruit walls have a number of air chambers and the fruits, seeds, and seedlings which can float on the water surface for pretty long time are dispersed to distant places by water current. Mangrove vegetations of tropical sea shores from Australia to East Africa include approximately the same species of plants. Similarly, the mangroves of West Asia show considerable resemblances with those of East Asia and East Africa. It is due, in part, to the fact that medium and temperature remain uniform throughout and partly due to the efficient means of dispersal or migration of plants. A littoral species of *Spinifex* (*S. quarrosus*), a member of Graminae commonly growing in the sandy saline sea shores in Andhra, shows peculiar type of fruit dispersal. In this plant, female inflorescence is spherical in shape and consists of many spikelets (Fig. 9·4). A number of stiff bractiolar bristles of the inflorescence help in the dancing and somersaulting of the inflorescence. When the seeds mature the globular and hairy inflorescence becomes bodily detached from the creeping plant and trails on the sandy substratum dropping its seeds at places. Finally the inflorescence with rest of fruits becomes buried in the mud.

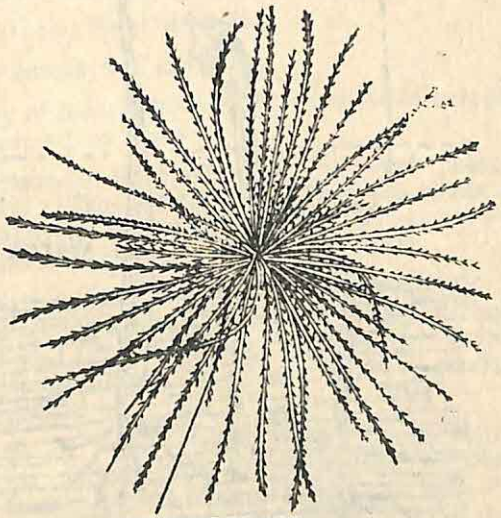


Fig. 9·4—Inflorescence of *Spinifex quarrosus*.

(*e*) **Viviparous mode of seed germination.** Halophytes or mangrove plants growing in the tidal marshes are met with the phenomenon of 'vivipary' which is defined as the germination of seeds while the fruits are still attached to mother plants (Fig. 9·5).

In *Rhizophora* plants, when the embryo reaches to advanced stage of development the massive club-shaped hypocotyl and terminal radicle pointing downwardly emerge out of the fruit. When the hypocotyl attains a length of several centimetres (about 50-80 cms), the seedling falls vertically down. Thus, the radicle and a part of hypocotyl become fixed in the mud and the remaining upper part of hypocotyl alongwith other embryonal parts, such as plumule and

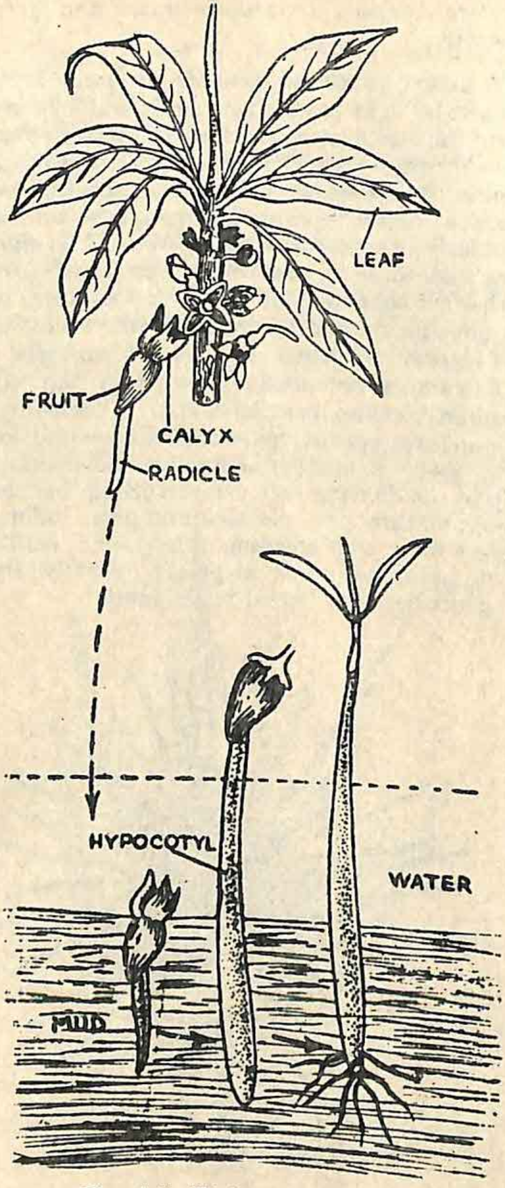


Fig. 9·5—Vivipary in *Rhizophora*.

cotyledons remains above the surface of mud or water. Within a few hours the radicle develops a tuft of roots and plumule also starts growing rapidly. Sometimes seedlings fall in deep water and they float on the surface of water vertically with hypocotyl pointing downwards. On reaching to shallow areas, the radicle becomes fixed in the soft mud and the plant starts growing very rapidly. It is noticed that high degree of salinity in the soil or water checks the germination of seeds. So the viviparous germination is a very significant adaptation in these plants to avoid the retarding effects of salinity on seed germination. Species of *Rhizophora*, *Aegiceras*, *Avicennia*, *Cassula*, *Ranansatia vivipara* are some of the common examples for vivipary.

3. Anatomical Features

The appearance and structures which characterise a certain growth of plants sum up to a great extent their ecological and physiological means of adaptation. Halophytes are no exception to this rule because of specific and typical structural characteristics which make them distinguishable from other groups of plants. These are :

1. Large cells and small intercellular spaces
2. High elasticity of the cell walls
3. Extensive development of water storing tissues
4. Smaller relative surface area (surface/volume ratio)
5. Small and fewer stomata
6. Low chlorophyll content.

Anatomy of halophytes reveals a number of xerophytic features in them. These are as follows :

(*i*) Presence of thick cuticle on the aerial parts of the plant body. The epidermis of xerosucculents and coastal halophytes is characterized by a cover of waxy layers in addition to thick cuticle (Uphof, 1941).

(*ii*) Leaves may be dorsiventral or isobilateral. They develop protected stomata which are not deeply sunken. Epidermal cells are thin-walled The palisade consists in several layers of narrow cells with intercalated tannin and oil cells.

(*iii*) Stems in the succulent plants possess thin-walled water storing parenchyma cells in them. Mucilage cells may be found in abundance. Epidermal cells of various mangrove species contain large quantities of tannins and oil droplets. Cortex is fleshy, several cells thick and in old stems it may become lacunar. Salinity causes extensive lignification of stele.

(*iv*) The leaves and stems of coastal halophytes are abundantly covered with various types of simple and branched trichomes, giving the plants a greyish appearance. The trichomes may exert a protective function in plants by:

(*a*) affecting water economy.

(*b*) affecting the temperature of their leaves, and

(*c*) preventing sea water droplets from reaching the live tissues of leaves.

(*v*) Leaves of many species of mangrove are dotted with local cork formation "cork warts". Leaves of *Sonneratia* and *Aegiceras* and *Nitraria* (a desert shrub), *Suaeda monoica* contain well developed aqueous tissue (Fig. 9·6A) (Mullan, 1932). Salt secreting glands may be found in some halophytes.

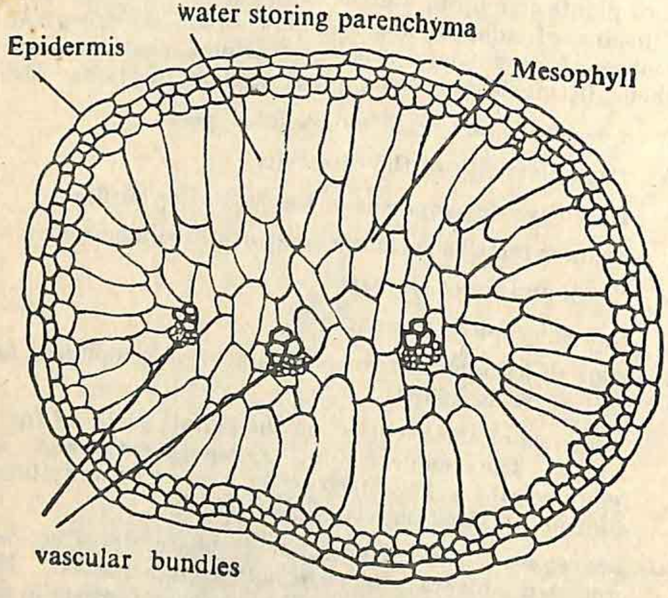


Fig. 9·6 A—T.S. of succulent of *Suaeda monoica* showing water storing parenchyma.

(*vi*) Pneumatophores develop a number of lenticels on their surface. The cortex is spongy and consists of extensively developed aerenchyma enclosing large air chambers. Highly developed air chambers are continuous with the stomata of leaves and with the cortex and primary phloem of the stems. Pneumatophores show variations in their internal structures. Generally they show conjoint, collateral vascular bundles with endarch xylem at maturity. Very young pneumatophores, however, show root features, *i.e*, exarch xylem and radial arrangement of vascular tissues (Fig. 9·6B). Generally the negatively geotropic breathing roots show features of stem and not of roots.

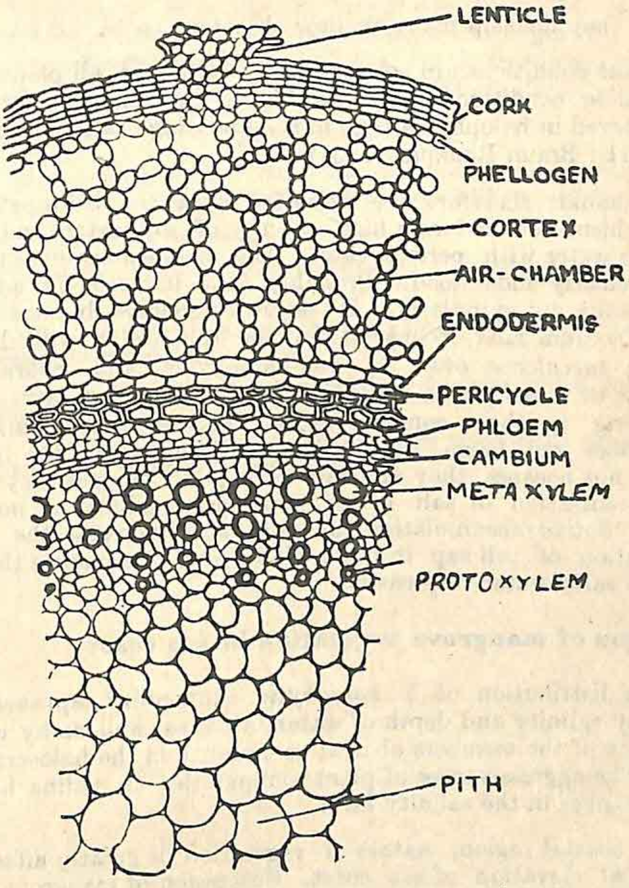


Fig. 9·6 B—T.S. of a pneumatophore.

4. Physiological adaptations in halophytes

Morphology and anatomy of the halophytes clearly show xeromorphic features in them. Now, these plants are growing in an environment where water is available to the plants in abundance then why xeromorphy develops in halophytes ? Previously physiological drought was believed to be the main cause of development of xeromorphy in halophytes, but recent physiological experiments on these plants have proved that xeromorphism in these plants is, apparently, an example of purposeless adaptation. Physiological experiments make it clear that the halophytes do not experience difficulties, whatsoever, in absorbing too saline water. This point is concluded taking into consideration the following reasonable facts.

(*i*) they show high rates of transpiration,

(*ii*) they show exudation of sap that contains dissolved salts,

(*iii*) they develop many shallow absorbing roots.

Saline conditions are not essentially "dry" for all plant species. Under saline conditions sometimes higher transpiration rates have been observed in halophytes than in neighbouring salt hating plants (Delf, 1911 ; Braun Blanquet, 1931).

It should, therefore, be admitted that the halophytes show xeromorphism for enduring high salinity of soil water and also for absorbing water with perfect ease. The significance of succulence is not so clearly understood. Probably, it is induced by accumulation of salts in cytoplasm. It seems reasonable because of the fact that sodium salts if present in the soil water will definitely stimulate succulence even in non-halophytes and characteristic succulence of some plants may disappear if they are grown on the soil lacking in these common salts. Excessive accumulation of sodium does not harm these plants. Halophytes grow in saline habitats not because they are salt loving, but because they tolerate high concentration of salt better than other plants of non-saline habitat. Active accumulation of salts also increases the osmotic concentration of cell sap in these plants and thus makes them able to absorb salty water very easily.

Succession of mangrove vegetation in sea coast

The distribution of a halophytic community appears to be limited by salinity and depth of water table, as well as by competitive ability of the members of next community in the halosere (Reed, 1947). The aggressiveness of plant communities in saline habitat is due to changes in the salinity level.

In coastal region, nature of vegetation is greatly affected by the gradual elevation of sea coast. Succession of mangrove formation in coast regions may take place very slowly in the following sequence :

(1) In the deep water generally true mangroves, *e.g.*, the species of *Avicennia* grow.

(2) When the bottom of the sea is slightly raised up, *Avicennia, Rhizophora, Ceriops, Bruguiera*, etc. form mixed mangroves vegetation in the shallow water.

(3) As the ground is exposed, true mangroves disappear and other halophytes, *e.g.*, species of *Aegiceras, Excoecaria* etc. gradually invade the land within short period. These halophytic communities are interspersed by salt tolerating succulents and the grasses make the soil fit for the cultivation of some crop plants. Several varieties of paddy, such as *Oryza sativa var, achra*, wild species of *Oryza coarctata* grow very well in these areas.

Succession of angiospermic halophytes varies also in each habitat in accordance with other ecological conditions besides salinity. Thus in reality, there is no general trend for development of various halophytic plant communities around the world and local variations are encountered in each specific site (Yoav Waisel, 1972),

QUESTIONS

1. What are halophytes ? Describe the various characteristic features of halophytes. How do they resemble xerophytes and hydrophytes ?

2. Write short notes on :

Mangrove, vivipary, Pneumatophore, Physiological adaptation of halophytes.

3. Discuss briefly the classification of halophytes and give an account of distribution of mangrove vegetation in India.

4. What are the various anatomical features which characterise halophytes ?

5. How is it that mangrove plants show xerophytic structures in spite of abundance of moisture in the habitat ?

10

PRINCIPLES OF PHYTOGEOGRAPHY, CLIMATE, VEGETATION AND BOTANICAL ZONES OF INDIA

Principles of phytogeography

Phytogeography or Plantgeography is a science which deals with the distribution of plants on or near the surface of the earth and water. On the basis of area of the earth surface occupied by the plants, the various taxa are categorised as under :

1. Wides.
2. Endemics.
3. Discontinuous species.

1. **Wides**. Plants widely distributed over the earth in definite climate zones and in different continents are referred to as wides. Cosmopolitan is applied for wides but in fact no plant is truly cosmopolitan in real sense of the term. *Taraxacum officinale* and *Chaenopodium album* are the common examples of the wides. Plants of tropical regions are called *Pantropical*. The plants of very cold climate may not only be found in the arctic regions but also in alpine zone of mountains in tropical and subtropical regions. These are called *arctic-alpine* plants.

2. **Endemics**. Plant species restricted to definite small regions are referred to as endemics. According to area of distribution; the species may be continental endemics (restricted to a continent), endemic to a country, provincial, regional or local endemics (restricted to valley, hills, islands, etc). The important factors responsible for endemism are as follows :

(*i*) Endemics may be the survivors of once widely distributed of ancestral forms for example, *Ginkgo biloba* (restricted to China and Japan), *Sequoia sempervirens*, (confined to coastal valleys of California, U.S.A.). *Agathis australis*, *Metasequoia* (confined to Singh valley in China). These species are called *Paleoendemics* or *epibionts.* A great majority of the endemic species belonging to this type have many fossil relatives. Because of little variability the endemics are adapted only to a particular environment and even if they reach to new areas, they fail to establish themselves in new environment.

(*ii*) The other endemics may be modern species which have not had enough time for occupying a large area through migration. They are called *neoendemics*. There are several such genera which are widely endemic or few species of which are endemic. Some of the well known endemic genera in Indian flora are ***Mecanopsis*** (Papaveraceae), Chloroxylon (Rutaceae), Catenaria and Butea (Papilionaceae), Caesulia (Compositae), Petalidium (Acanthaceae) etc. *Elettaria repens* (Zingiberaceae), Piper longum (Piperaceae), *Piper nigrum* (Piperaceae), *Ficus religiosa* (Moraceae), *Shorea robusta* (Dipterocarpaceae), Venda caerulea (Orchidaceae), *Salmalia malabarica* (Bombacaceae), *Eleusine coracana* (Gramineae) are the well known endemic species of Indian flora.

Endemism results from the failure on the part of species to disseminate its seeds, fruits, spores or propagules because of existence of great barriers like mountains, oceans and large deserts. The oceanic islands which are isolated from rest of the world by large expanses of water abound in endemic species and water barrier checks the migration of these species outside their original habitat.

3. **Discontinuous species**. There are plants which occur at two or more distant places separated by overlands or oceans, hundreds or thousands of miles. Such distribution is called discontinuous or disjunct. The significant phytogeographical causes for discontinuous distribution are as follows :

(*i*) The species might have evolved at more than one place and they failed to migrate outside their original habitats because of barriers.

(*ii*) The species which were once widely distributed in the past disappeared from certain areas and are now surviving in some distant pockets.

(*iii*) **Continental drifts**. The present continents on the earth are not the same as they were in geological past, as for example, during the mesozoic era South America, Africa, India, Polynesia, Australia and Antarctica were all united to form a large landmass called *Gondwanaland* which was having its characteristic flora and fauna. Similarly, there was a northern landmass called *Laurasia* separated from Gondwana land by Tethys sea. Because of geological disturbances the large landmasses gave rise to widely separated continents all having some common species.

(*iv*) The climate may also be a reason for discontinuity in distribution of species. Plants having specific climatic requirements are found in widely separated areas with similar environmental conditions, as for example, plants of arctic regions are also found in alpine zone of high mountains in tropics and subtropics. *Salix* and *Silen* species show discontinuous distribution in arctic-alpine regions.

Factors affecting distribution of species

Several factors are known to affect the geographical distribution of plant species, some of which are as follows :

1. Geological history and distribution.
2. Migration.
3. Ecological amplitude.

1. **Geological history and distribution.** The place where a species first originated is called its centre of origin. Evolution of species is a slow but continuous process. Some of species in present day flora are quite old while a great majority of them are recent in origin. The process of species differentiation involves (*i*) hybridization between the related species as well as mutation and (*ii*) the natural selection from the hybrid and mutant populations. In the selection process not all the hybrids and mutants are selected by nature and only the fittest individuals which find the habitat conditions within their ecological amplitudes are selected and the individuals least fit are eliminated. Changing climate has also played important role in the origin of new species. In the course of evolution several old species became extinct. Some of which can be found today as fossils. The fossils provide direct evidence for the existence of various taxa.

2. **Migration.** The newly evolved species starts migration in newer areas and side by side it undergoes further evolutionary changes. The dispersal of germules and propagules is brought about by several agencies like wind, water, glaciers, insects, animals even man. The dispersal is followed by *ecasis.* Migration may be adversely affected and sometimes even totally stopped by some factors called *migration barriers.* Barriers in the dispersal of species may be classified as ecological or environmental and geographical. The climate, an ecological barrier, plays important role in distribution and establishment of species. Unsuitable climatic condition or change of climate in particular area forces the species to migrate from one place to another and the failure of some species to migration leads them to gradual extinction. Besides climate, there are geographical barriers, as for example, high mountains, vast oceans or deserts. The fresh water plants for example cannot be dispersed across oceans if the propagules are suitable only for fresh water dispersal and similarly germules or propagules of land plant from one country cannot reach to other country separated by vast oceans and mountains. Species are called native in the place of its occurrence if it originated there. Outside the area of its origin, the species is referred to as exotic. Exotic species reach to new area through migration. If any species is introduced intentionally in new area by man then it is called introduced species.

3. **Ecological amplitudes and distribution.** Environmental conditions not only influence the life and development of a plant but also determine the presence or absence, vigour or weakness and relative success or failure of various plants in a particular habitat. Each plant species of a community has a definite range

of tolerance towards physical and biological environment (its ecological amplitudes) of the habitat.

The presence of species at a particular place, no doubt, indicates that the environmental conditions of that habitat are within its ecological amplitude but the absence of a species from one place does not necessarily indicate that the environment is not suitable for that species.

The ecological amplitude is governed by genetic set up of the species concerned and thus different species have different ecological amplitudes which may sometimes overlap only in certain respects. Further, some species may occur at different geographical regions as and when the conditions fall within its ecological amplitude. As for example, some plants of temperate region, say conifers, may be found in alpine zone of high mountains in tropical and subtropical regions. The other consideration in ecological amplitude as a factor in plant distribution is its change with time. In sexually reproducing plants the hybridization between related species results in offsprings with new genetic composition. With the change of environment the plant species also make adjustments with new environment by shifts in their ecological amplitudes facilitated by changes in the genotype. Within a species there may occur several genetically different groups of individuals (populations) which are adjusted to particular set of ecological conditions. These populations are called ecotypes or ecological races or ecological population. In *Euphorbia thymifolia* for example, there are two major population—one is calcium loving or calcicole and the other type is calcium hating or calcifuge. Similarly ecological races of *Xanthium strumarium* and *Ageratum conyzoides* differ in their photoperiodic requirements. The existence of ecotypes within the species widens the area of its geographical distribution.

Climate and Vegetation of India

Atmospheric and meteorological influences principally moisture temperature, wind, atmospheric pressure and evaporation of a region collectively form the climate. Climate has marked influences on the growth, distribution and development of vegetation types in India. India lies north of equator between latitudes 6° and 38°. The Himalayan mountain is present in the north. India is surrounded on its south, east, and west by Indian ocean, Bay of Bengal and Arabian sea respectively. The country as a whole can be divided into three main parts : (*i*) The mountain wall, (*ii*) The plains of northern India, and (*iii*) the plateau of Peninsular India.

Climate of India is not homogeneous throughout but it is highly variable. The country stands in the tropical and subtropical belts and the climate is greatly modified by oceans and mountain ranges. The climate in South and East is more typically tropical rainy, near temperate at high altitudes in the north (Kashmir) and semiarid and arid (dry hot) in the north western part. The temperature is usually high throughout the year in most part of the country except at high altitude in extreme north where snowfall occurs during winter and temperature goes below 0°C for short periods.

The amount of rainfall varies greatly in different periods of the year and in different parts of the country ; some parts receiving above 400 cm annual rainfall and some receiving as little as 20 cm annual rainfall or even no rains at all in some years. The distribution of annual rainfall in India is shown in Fig. 10·1.

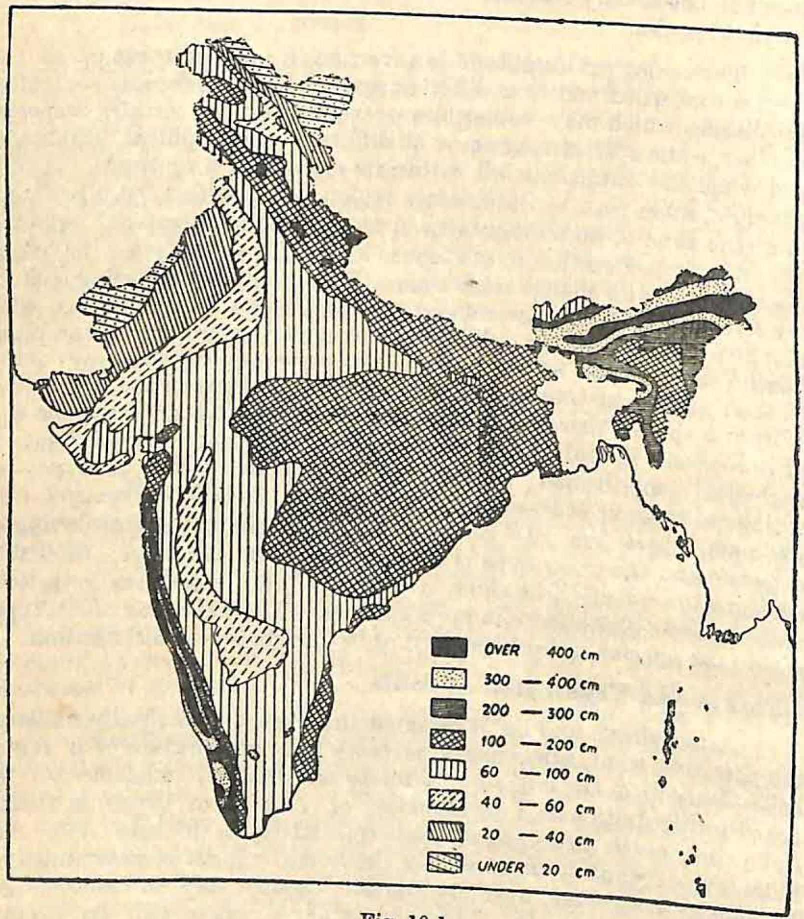


Fig. 10·1.

Sir John Elliot was the first man to prepare a detailed climate map of India and later on Kendew (1952), C.W.B. Normand (1937), Stamp (1946) and Waheed Khan (1959) also described the seasons and the climates of India. The meteorological department of Government of India has adapted the following 4 seasons :

1. Cold weather season (from January to February).
2. Hot weather season (from March to middle of June).
3. Rainy season (from middle of June to middle of September).
4. Season of retreating monsoons (from middle September to December).

1. **Cold weather season**. The season starts in January and persists up to February. In this season, the atmospheric temperature goes very down, chilly winds blow from west or north west to east or southeast direction, air is dry, fresh and the sky is clear. The cyclonic rains are prevalent at the top of Peninsula, foot hills of Himalayas and the margins of the plains in the Punjab and extending up to U.P. and southward, into Rajasthan, Maharashtra and M.P. The winter rain, although light, greatly influences the growth of vegetation because runoff is very little, evaporation rate is very low and a large amount of it is available to the root zone.

2. **Hot weather season**. In the beginning of March, temperature starts rising and humidity decreases. The onset of summer season is indicated by leaf-fall and almost simultaneous appearance of new leaves and blooming in many plants as Mango, Amaltas (*Cassia fistula*), Gulmohar (*Delonix regia*) and so on. The temperature continues to rise till middle of June, when mercury level may touch 45° to 49°C in upper Gangetic plains. The high temperature causes decrease in atmospheric pressure in most parts of the country. This results in hot winds which below from south and southeast to north and northwest. These winds carry clouds with them.

3. **Rainy season**. This season starts with the bursting of the advancing monsoon winds during the middle of the June or beginning of July. The monsoon winds arising in the Indian ocean and passing over the Bay of Bengal enter the Gangetic plains and produce maximum rains in the north eastern parts of the country and heavy rains in the plains of Bengal, Bihar, U.P., Orissa, Punjab, part of M.P., Kashmir etc. The amount of rainfall decreases towards west. The annual rainfall in these regions ranges between 100 and 200 cm. Parts of Punjab, Rajasthan, Gujarat and Maharashtra receive only scanty rainfalls and a part of Rajasthan west of Aravalli ranges shows arid desert conditions with almost no rains in some years. The monsoon winds arising over Arabian sea produce heavy rains in South India and western coasts and lesser rains in the interior. The rain is not continuous throughout the season but it continues upto middle or end of September interrupted by bright or cloudy rainless days. The mountain ranges play significant role in the distribution of rainfall. Aravalli ranges are largely responsible for the arid climate in western Rajasthan.

4. **Season of retreating monsoons**. Towards the end of September the monsoon winds start retreating and produce only occasional showers. The sky becomes clear. The temperature decreases gradually and by the end of December cold sets in. Due to sudden variations in temperature local cyclones develop in the region of Bay of Bengal and the east coast of Tamil Nadu and cause isolated rains in certain areas.

Climatic regions of India

On the basis of rainfall India can be roughly divided into the following four climatic zones :

1. **Wet zone.** The average annual rainfall in this zone is more than 200 cm. Wet zone comprises of Western ghats including western coastal part of Bombay, Karnatak and Kerala, Assam, eastern half of Bengal, Tarai region of U.P., Orissa, parts of M.P. and north Bihar. Natural vegetation includes normally evergreen and semi-evergreen tropical forests in the west coasts and Assam but dry deciduous forests (mostly *Shorea robusta*) in other parts. Rice is the main agricultural crop.

2. **Intermediate zone.** The mean annual rainfall in this zone is above 100 cm but less than 200 cm. The zone comprises south west Bengal, Bihar, Orissa, part of M.P., east U.P., north eastern Andhra Pradesh, eastern slopes of western ghats and east Tamil Nadu. Natural vegetation includes dry deciduous forests and dry deciduous thorn forests and scrubs. Rice is the major agricultural crop.

3. **Dry zone.** This zone receives annual rainfall between 50 and 100 cm and includes western U.P., N.E. Punjab, Delhi, S.E. Bombay, Eastern part of Rajasthan, and western half of Andhra. Natural vegetation includes shrubs and thorn scrubs. Wheat and millets are the major agricultural crops.

4. **Arid Zone.** This zone receives rainfall less than 50 cm in a year and includes south western parts of Rajasthan and Punjab, N.E. Bombay and N.E. Gujarat. Natural vegetation includes thorny scrubs and short-lived herbs.

Vegetation of India

Vegetation is the total plant cover of a region or area or place. Geographically, India is a tropical country but whole of the Gangetic plains lies outside the tropics. It has strong monsoonic climate and differs from other tropical regions of the world. As pointed out earlier, there are 4 climatic regions in India which are characterised by different types of natural vegetation. Several factors are responsible for the occurrence of a variety of vegetational types in this country. Besides the climatic factors, soils upon which vegetation is found greatly determine the nature of vegetation. Vegetation in this subcontinent may be influenced by biotic factors as well as human culture for a long time. The plant formations determined by specific and continuous operation of man himself are called anthropogenic formations.

Some of important criteria used in the classification of vegetation are Physiognomy, structure, function, composition, dynamics (successional phenomenon), habitat relations and history. Fosberg (1961) found that the structure and function are the most satisfactory criteria for classification of vegetation. Champion (1938) gave the first complete classification of vegetation of India. Since then many workers have modified Champion's classification and some of them have given their own classification. Fosberg (1961) recognised the following three major structural groups in the vegetation of India.

1. Closed vegetation.
2. Open vegetation.
3. Sparse vegetation.

Indian vegetation presents a varied assemblage of plant communities and includes several exotic elements, especially from China, Japan, Malaya, Africa, Tibet and Siberia. The following recognised plant formation types cover whole of India :

1. Forests.
2. Grassland.
3. Vegetation of ponds and lakes.
4. Vegetation of sea shore.

1. Forests

Hanson (1962) defines forest as "a stand of trees growing close together with associated plants of various kinds". The following types of forests are found in India which cover nearly 23 per cent of the total area of Indian territory.

I. **Tropical forest.** A great majority of the forests found in India are of this type. Tropical forests are of two types :

(*A*) Tropical moist forests.

(*B*) Tropical dry forests.

(*A*) **Tropical moist forests.** These are further classified into the following three types on the basis of relative degree of wetness :

(*i*) Tropical moist evergreen forests.

(*ii*) Tropical moist semi-evergreen forests.

(*iii*) Tropical moist deciduous forests.

(*i*) **Tropical moist evergreen forests** : These are also called tropical rain forests. In India such forests are found in very wet regions receiving more than 250 cm average annual rainfall. These are climatic forests having luxuriantly growing lofty trees which are more than 45 metres in height. The shrubs, lianas (woody climbers) and epiphytes are abundant because of high rainfall. These forests are found in Andaman and Nicobar Islands, western Coasts and parts of Karnataka (N. Canara). Annamalai hills (Koorj), Assam, Bengal. Detailed account of this is given in the description of mesophytes.

(*ii*) **Tropical moist semi-evergreen forests.** These forests are found along western coasts, eastern Orissa and upper Assam where annual rainfall is between 200 and 250 cm. They are characterised by giant and luxuriantly growing intermixed deciduous and evergreen species of trees and shrubs. The important plants in these forests are the species of *Terminalia*, *Bambusa*, *Ixora*, *Dipterocarpus*, *Garcinia*, *Sterculia*, *Mallotus*, *Calamus*, *Albizzia*, *Elettaria*, *Pothos*, *Vitis*, *Shorea*, *Cinnamomum*, *Bauhinia*, *Albizzia*, etc. Orchids, ferns, some grasses and several other herbs are also common.

(*iii*) **Tropical moist deciduous forests.** These cover an extensive area of the country receiving sufficiently high rainfall (100 to 200 cm) spread over most of the year. The dry periods are of short duration. Many plants of such forests show leaffall in hot summer.

These forests are found along the wet western side of the Deccan plateau, *i.e.*, Bombay, N.E. Andhra, Gangetic plains and in some Himalayan tracts extending from Punjab in west to Assam valley in the east. The forests of Southern India are dominated by Teak (*Tectona grandis*), *Terminalia paniculata*, *T. bellenica*, *Grewia tillaefolia*, *Dalbergia latifolia*, *Lagerstroemia*, *Andina cordifolia*, etc are the other common species in forests of South India. In north, they are dominated by Shal (*Shorea robusta*). Some other common associates of Shal are *Terminalia tomentosa*, *Dellenia* species, *Eugenia* species, *Boswellia* species, *Mallotus philippinesis*. These forests produce some of the most important timbers of India. Grasses become important both in seral stages and in the areas under fire.

B. **Tropical dry forests**. These are classified into the following types :

(*i*) Tropical dry evergreen forests.

(*ii*) Tropical dry deciduous forests.

(*iii*) Tropical thorn forests.

(*i*) **Tropical dry evergreen forests**. These forests are found in the areas where rainfall is in plenty but dry season is comparatively longer. The trees are dense, everygreen and short (about 10 to 15 metres high). These forests are found in eastern part of Tamil Nadu in east and west coasts. The common plant species are much the same as in Tropical moist evergreen forests. Species of *Maba*, *Calotropis*, *Pabatta*, *Feronia*, *Canthium*, *Zizyphus*, Randia etc. are most common. Bamboos are absent but grasses are common.

(*ii*) **Tropical dry deciduous forest**. These forests are distributed in the areas where annual rainfall is usually low ranging between 70 and 100 cm, such as, Punjab, U.P., Bihar, Orissa, M.P. and large part of Indian peninsula. The largest area of the country's forest land is occupied by Tropical dry deciduous forests. The dry season is long and most of the trees remain leafless during that season. The forest trees are not dense, 10 to 15 m in height and undergrowth is abundant. In north, the forests are dominated by shal and in south by teak (*Tectona grandis*). The common constituents of these forests in South are *Dalbergia*, *Terminalia*, *Dillenia*, *Acacia*, *Pterospermum*, *Diospyros*, *Anogeissus*, *Boswellia*, Chloroxylon, *Bauhinia*, *Hardwickia*, *Gymnosporia*, *Zizyphus*, *Moringa*, *Dendrocalamus* and so on. The other species of trees and shrubs of Sal dominated forests of northern region are *Terminalia*, *Semicarpus*, *Buchnania*, *Carissa*, *Modhuca*, *Acacia*, *Sterculia*, *Lannea*, *Salmalia*, *Adina*, *Bauhinia* *Aegle*, *Grewia*, *Phyllanthus*, etc.

(*iii*) **Tropical thorn scrubs.** These forests occur in the areas where annual rainfall is between 20 to 70 cm, dry season is hot and very long. They are found in South Punjab, most of Rajasthan and part of Gujarat. The vegetation in these regions occur only along the rivers. The land away from the rivers and devoid of irrigation is mostly sandy and devoid of trees. The vegetation is of open type consisting of small trees (8 to 10 m high) and thorny or spiny shrubs of stunted growth. The forests remain leafless for most part of the year and are sometimes called thorn scrub or scrub jungles. There is luxriant growth of ephemeral herbs and grasses during the rainy season. Towards the desert region the vegetation diminishes and in arid parts there is almost no vegetation. The species of *Acacia*, *Cassia*, *Calotropis*, *Randia*, *Albizzia*, *Zizyphus*, *Erythroxylon*, *Euphorbia*, *Cordia*, *Prosopis*, *Salvadora*, *Aegle*, *Gymnosporia*, *Atriplex*, *Grewia*, *Asparagus*, *Berberis*, *Butea*, *Kochia*, *Leptadenia*. *Capparis*, *Adhatoda*, etc. characterise the plant formations of semiarid regions of India.

Champion (1938) named the natural vegetation of desert as *tropical thorny forest*. Bharucha (1955) divided the Rajasthan desert into the following vegetational zones :

(*i*) Area of shifting sand dunes at and around Jaiselmer and Bikaner.

(*ii*) Area of established sand dunes near Jodhpur.

(*iii*) Sand stone rocks covered by xerophytic plants like *Euphorbia nerifolia*.

(*iv*) Area of Halophytic vegetation.

(*v*) Sandy-loam soil vegetation.

II. **Sub-tropical forests**. These forests are found in the region of fairly high rainfall but where temperature differences between winter and summer are less marked. Winter generally goes without rains. They are found up to the altitude of about 1500 metre in south and up to about 1800 metre in the north. In composition, subtropical forests are almost intermediate between tropical forest and temperate forests and a sharp demarcation can seldom be made between tropical and subtropical or subtropical and temperate forests. These forests have been grouped into the following three types :

(*i*) Wet hill forests.

(*ii*) Dry evergreen forests.

(*iii*) Pine forests.

(*i*) **The wet hill forests.** They are found at Mahabaleshwar, Coorg, Karnatak, parts of Assam, Matheran, Panchmarhi and other parts of M.P. The important plants found in the wet hill forests of south are the species of *Eugenia*, *Randia*, *Terminalia*, *Eleagnus*, *Murraya*, *Gymnosporia*, *Atylosia*, *Ficus*, *Pterocarpus*, *Lantana*, etc.

while those of the north are *Castonopsis*, *Calamus*, *Almus*, *Quercus*, *Betula*, *Schima phoebe*, *Cedrella*, *Garcinia*, *Populus*, etc.

(*ii*) **Dry evergreen forests.** They occupy the foot-hill areas of Himalayas. The common constituents of vegetation are *Acacia modesta*, *Olea Cuspidata*, etc.

(*iii*) **Pine forests.** They are found mostly in western and central Himalayas and in Assam hills. The forests are dominated by species of *Pinus* (*Pinus khasya*) and (*P. roxburghii*). Species of *Quercus*, *Berberis*, *Carissa*, *Bauhinia* may also occur rarely in pine forests.

III. **Temperate Montane forests.** These forests occur in the Himalayas at the altitude from 1800 to 3800 metres where humidity and temperature are comparatively low. Montane forests have been classified into the following three types on the basis of moisture regime :

(*i*) Wet temperate forest.
(*ii*) Moist temperate forest.
(*iii*) Dry temperate forest.

(*i*) **Wet temperate forests.** These are found in Himalayas extending from Nepal to Assam at the altitude of 1800 to 3000 m, as well as in some parts of South India (Nilgiris). The forest in south are evergreen and are called Sholas. The forests are dense with closed canopy and the trees may be 15 to 20 m high. Epiphytes are in abundance. Important plants constituting the vegetation in Eastern Himalayas are species of conifers, Hopea, *Balanocarpus*, *Elaeocarpus*, *Artocarpus*, *Pterocarpus*, *Myristica*, *Hardwickia*, *Salmelia*, *Dioscoria*, members of family Compositae, Rubiaceae, Acanthaceae and Leguminosae from the undergrowth.

(*ii*) **Moist temperate forests.** These forests develop in the areas of lesser rainfall. The trees are high sometimes up to 45 metres. The dominant elements of vegetation are Oak and Conifers. Undergrowth is shruby and consists of deciduous species of *Berberis*, *Spiraea*, *Cotaneaster*, etc.

(*iii*) **Dry temperate forests.** These forests dominated by Rhododendrons, oaks and conifers form a narrow belt at the altitude from 3000 to 4000 m in the western Himalayas extending from a part of U.P. through Himachal Pradesh and Punjab to Kashmir. The other commonly found species belong to genera as *Daphne*, *Desmodium*, *Indigofera*, *Artemisia*, *Cannabis*, *Plectranthus*, *Fraxinus*, several epiphytic mosses, Lichens etc.

(*iv*) **Alpine forests.** Alpine vegetation has been classified into the following three types :

(*i*) Alpine forests.
(*ii*) Alpine moist scrubs.
(*iii*) Alpine dry scrubs.

(*a*) **Alpine forests.** Plants growing at the altitude of 2900 to 6000 m are called alpine plants. In India, alpine flora occurs in Himalayas between 4500 and 6000 metres. At lower level alpine forests consist of dwarf trees with or without conifers and at higher level scrubs and only scattered xerophytic shrubs are left to merge with alpine meadows. The common plants of alpine forests are *Abies*, *Pinus*, *Junipers*, *Betula*, shruby Rhododendrons, *Quercus*, *Pyrus*, Salix etc.

(*b*) **Alpine moist scrubs.** This type of vegetation is distributed extensively throughout the Himalayas above 3000 metres. It is most often dense and composed of everygreen dwarf *Rhododendron* species but with some Birch and other deciduous trees. Mosses and ferns cover the ground with varying amounts of alpine shrubs, flowering herbs and ferns. Alpine pastures include mostly mesophytic herbs with very little grass.

(*c*) **Alipine dry scrubs**. These are open xerophytic formations spread in U.P., Himachal Pradesh, Punjab and Kashmir. Species belonging to *Artemisia*, *Potentilla*, *Kochia*, *Juniperus* predominate in the vegetation which develops generally on lime stone rock.

2. Grassland vegetation

According to Ecological Society of America (1952), "grassland is a community dominated by grasses or grass like plants". Natural grasslands occur in temperate zone with annual rainfall 25 to 80 cm, while in tropics they may be found in areas receiving rainfall up to 150 cm. The favourable conditions for development of a stable grassland are frequently rainfall and sufficient warmth during the growing season. Grasslands do not form a prominent feature of vegetation in tropical part of India because of the following reasons :

(*i*) In the moist lowlands, grasses face very tough competition from trees and shrubs.

(*ii*) In the drier parts, the conditions are so severe that they do not permit the extensive development of grasslands. Indian grasslands are not climax formations but they have developed secondarily under the influence of two factors, namely edaphic and biotic. In most cases, grasslands are maintained in their present seral stage due to biotic influences. Fire alone or fire coupled with grazing and browsing may be very potent factors causing the development of grasslands in forest areas. If a grassland exists in forest territory for a number of years, the forest growth cannot eliminate it even if the fire factor is absent. There are several grassy flats and grassy plains of seral nature in Nilgiri's, Khasi hills, Naga hills. At elevations higher than 800 metres, the rainfall is heavy, the soil is dark in colour and rich in humus, and the vegetation consists of grasses which grow forming tufts at lower altitude and a turf at higher altitude. In swampy places above 1800 metre elevations, species belonging to Cyperaceae are in abundance. In the regions where forests are destroyed by fire, vegetation consisting of tall grasses with scattered trees (*i.e.*, Savannahs) develop.

The Tropical grasslands of India may be classified into the following types :

(*i*) **Xerophilous grasslands.** These are found in dry regions of North-West India under semidesert condition. The common species of xerophilous grasslands are *Andropogon contortus, Cenchrus ciliaris, C. barbatus*, etc.

(*ii*) **Mesophilous grasslands.** They are also called Savannahs. They are extensive grassy flats or grassy plàins typically occurring in moist deciduous forests of U.P. Dominant species of such grassy lands may be *Saccharum munja, S. narenga*, etc.

(*iii*) **Hygrophilous grasslands.** These are called wets savannahs adapted to very wet soil.

All these types being biotically controlled are inferior to temperate grasslands and suffer considerably from monsoon nature of climate, and lack of proper legume mixture.

Indian grasslands have been divided into the following major types by R.O. Whyte (1957). The geographical distribution and environments of these grassland types are given in the following table :

Major grassland types	*Environments*	*Regions of distribution*
1. *Sehima—Dichanthium*	Black soil	Hyderabad, Bombay, M.P., Andhra Pradesh, Tamil Nadu, S.E. U.P.
2. *Dichanthium Cenchrus*	Sandy loam soil	Punjab, Delhi, Rajasthan, Gujarat, Cutch, Eastern U.P., Bihar.
3. *Phragmites—Saccharum*	Marshy areas	Terai U.P., Bihar, Bengal, Assam, Sunderbans and other delta.
4. *Bothriochloa*	High rainfall and low lying areas	Lonavala tract of Maharashtra.
5. *Cymbopogon*	Low hills	Western Ghats, Vindhyas, Satpura, Aravali range, Orissa up to 100 mile belt.
6. *Arundinella*	High mountains	Western Ghats, Nilgiris, Himalayas, Eastern Punjab, Himachal Pradesh up to 2000 miles.
7. *Deyeuxia Arundinella*	Mixed temperate climate	Himalayas, Kashmir, U.P., Bengal and Assam.
8. *Deschampsia-Deyeuxia*	Temperate alpine climate	Himalayas, Kashmir, above 2500 metre.

3. Vegetation of ponds and lakes

The aquatic vegetation is affected by supply of O_2, CO_2, mineral salts, nature of substratum, depth of water, temperature and light intensity. Some of the common aquatic plants belonging to different types of hydrophytes which are found in the ponds and lakes of India have been discussed in "Hydrophytes" under the chapter "Plant adaptations".

4. Vegetation of sea shore

(*a*) **Mangrove or littoral forests.** The mangrove flora occurs near the estuaries. In India, these forests are found near Calcutta in Hughly river, and Sunderbans. Mangrove vegetation is discussed in detail in a separate chapter.

(*b*) **Vegetation on sand dunes.** Sand dunes are found on flat coast where only such plants grow as can tolerate the exposure of moving sand, high diurnal temperature, strong winds and some salts and can grow keeping pace with the constant accumulation of sand to avoid burial. *Ipomoea pes-caprae* develops in abundance in sand dunes.

(*c*) **Beach jungles.** These are found near sea coasts in Andamans, Sunderban, Orissa, Tamil Nadu, Kerala and Bombay. Soil is sandy having large amount of lime and salts but poor in other mineral contents. The temperature is moderate and water table is only a few metres deep. Succulents and sclerophyllous xerophytes as *Pandanus*, *Chrocus nucifera* etc. are of common occurrence.

BOTANICAL ZONES OR PHYTOGEOGRAPHIC REGIONS OF INDIA

Vegetation of any place is modified by the environmental factors ; climate, geology and biotic factors. The great area of Indian subcontinent has wide range of climate and corresponding diversity in the vegetation. Important contributors who attempted to analyse the vegetation of India are Hooker (1907) and Chatterjee (1939). Hooker (1907) analysed vegetation of India (before partition) into the following Botanical provinces :

(1) Eastern Himalayas;

(2) Western Himalayas;

(3) Indus plain;

(4) Gangetic plain;

(5) Malabar;

(6) Deccan;

(7) Assam; and

(8) Maldives.

Chatterjee (1939) modified the Hookar scheme and suggested the following Botanical provinces in undivided India, excluding Malaya and Ceylon. These provinces are as follows :

(1) Western Himalayas,
(2) Eastern Himalayas,
(3) Central Himalayas (now in Nepal),
(4) Gangetic plains,
(5) Indus plain,
(6) Deccan,
(7) Malabar,
(8) Assam,

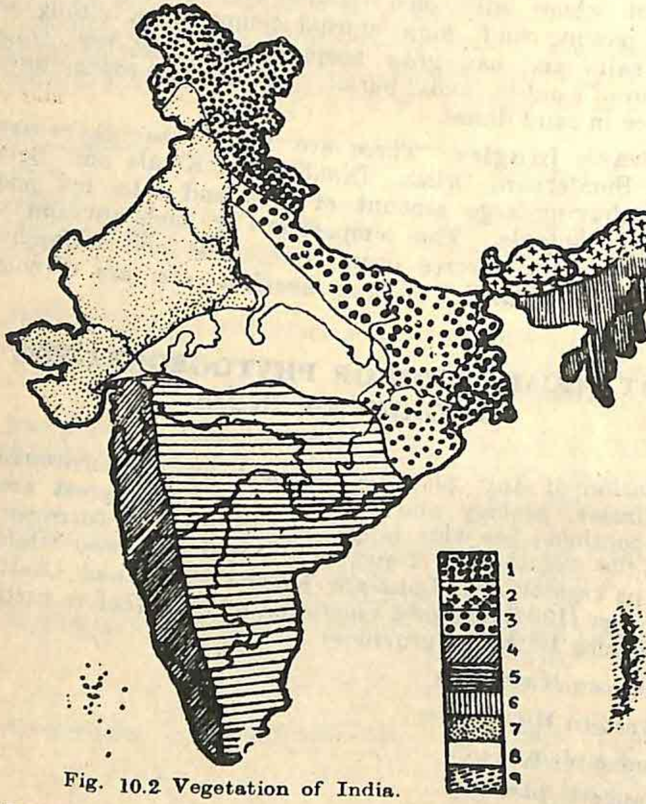


Fig. 10.2 Vegetation of India.

1. Western Himalayas, 2. Eastern Himalayas, 3 Gangetic plain, 4. Western Coast of Malabar, 5. Deccan, 6. Assam, 7. Indus plain, 8. Central India, 9. Bay Islands of Andaman and Nicobar.

(9) Upper Burma and

(10) Lower Burma.

Recently India (after partition) has been divided into the following botanical provinces by D. Chatterjee (1962), Fig. 10.2.

(1) Western Himalayas

(2) Eastern Himalayas

(3) Indus plain

(4) Gangetic plain

(5) Central India

(6) Deccan

(7) Western coast of Malabar

(8) Assam

(9) Bay Islands of Andaman and Nicobar (In India).

(1) Western Himalayas

The northern part of our country is bounded by highest ranges of Himalayas which is one of the important botanical regions of the world with climate and vegetation ranging from truly tropical near the low altitudes to temperate arctic types at the high altitudes. The northern mountain division can phytogeographically be divided into western, central and eastern zones.

Western Himalayas consist of north Kashmir, south Kashmir, a part of Punjab and Kumaon. This zone is wet in outer southern ranges and slightly dry in inner northern zone. The average annual rainfall in this region is from 100 to 200 cm. Snowfall occurs in this region during winter season. The region may be divided into three subzones (Fig. 10.3).

(*i*) *Submontane zone* or *lower region* or tropical and subtropical belts (upto about 1500 metres altitudes from the sea level).

(*ii*) *Temperate zone* (from 1500 metres to 3500 metres altitudes)

(*iii*) *Alpine zone* (above 3500 metres and upto the line of perpetual snow).

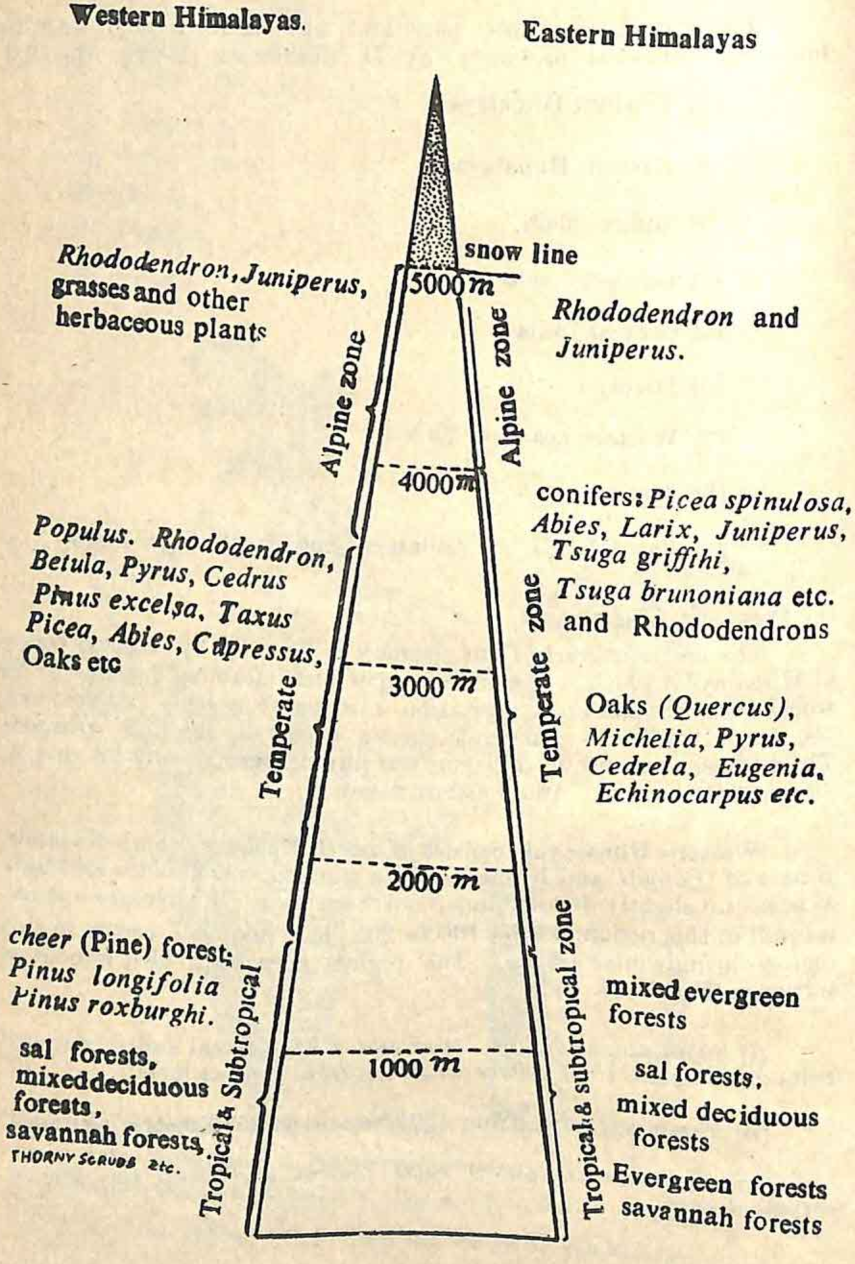

Western Himalayas.
Eastern Himalayas
snow line
5000 m
Rhododendron, Juniperus, grasses and other herbaceous plants
Alpine zone
Alpine zone
Rhododendron and Juniperus.
4000 m
conifers: Picea spinulosa, Abies, Larix, Juniperus, Tsuga griffithi, Tsuga brunoniana etc. and Rhododendrons
Populus. Rhododendron, Betula, Pyrus, Cedrus Pinus excelsa, Taxus Picea, Abies, Cupressus, Oaks etc
Temperate
Temperate zone
3000 m
Oaks (Quercus), Michelia, Pyrus, Cedrela, Eugenia, Echinocarpus etc.
2000 m
cheer (Pine) forest; Pinus longifolia Pinus roxburghi.
Tropical & Subtropical
Tropical & subtropical zone
mixed evergreen forests
1000 m
sal forests, mixed deciduous forests, savannah forests, THORNY SCRUBS etc.
sal forests, mixed deciduous forests
Evergreen forests savannah forests

Fig. 10.3—Main types of vegetation at different altitudes in the Western and Eastern Himalayas.

(i) Submontane or Lower region or tropical and subtropical belts. It includes outer Himalayas particularly regions of Siwaliks and adjoining areas where annual average rainfall is over 100 mm. This zone ranges between 300 metres and 1500 metres. In this zone forests dominated by timber trees of *Shorea robusta* are common. Other important tree species are *Salmalia malabaricum*, *Butea monosperma*, *Acacia catachu* and *Zizyphus* species. In the swampy areas, *Dalbergia sisso* (Shisham), *Ficus glomerata*, *Eugenia jambolana* are common in occurrence. In west dry regions, sal trees are replaced by xeric plants particularly *Zizyphus*, *Carissa*, *Acacia*, and thorny *Euphorbias*. At higher elevation, around 1000 to 1500 metre altitude, cheer (pine) forests are also found at certain places. The common species of pine are *Pinus longifolia* and *Pinus roxburghii*. Ground vegetation is scanty.

(ii) Temperate zone. It commonly ranges at the altitudes from 1500 to 3500 metres adove the sea level. Oaks are dominant along with *Populus*, *Rhododendron*, *Betula*, *Pyrus* *Pinus excelsa*, *Cedrus deodara*, *Picea*, *Abies*, *Cupressus*, and *Taxus baccata* are found in the heavy rainfall region (between 1600 and 1800 m). Herbs are also common in this region. Common herbs are *Ranunculus hirtila*, *Polygonum*, *Pedicularia*, *Potentilla argyrophylla*, *Primula*, *Delphinium*, *Clematis*, crucifers and many members of compositae. In cultivated drylands of Punjab, wheat and barley are main crops. In Kashmir, *Bitula* (Birch), salix (cane), *Populus* (Poplar) are of common occurrence. Besides these, *Quercus semicarpifolia*, *Q. dilatata*, *Aesculus indica* (chestnut), and many conifers are commonly met with in this regicn. In wet Kashmir, rice cultivation is common, Keshar or saffron (*Crocus sativus*), apples, peaches, walnut, almonds and other fruits are important economic plants of Kashmir region.

(iii) Alpine zone. Above the altitude of 3500 metres and up to snowline (about 5000 m) is alpine zone. The vegetation consists of evergreen conifers and some low and broad leaved trees. The vegetation of this region is characterized by cushion habit, dwarf nature and gregarious habit. In lower alpine region, shrubby forests are common which may be (*a*) Birch—fir forest which is fairly dense and is mixed with evergreen shrubby *Rhododendron* at higher level and (*b*) Brich--*Rhododendron* forests in which *silver fir*, *Betula*, *Rhododendron* and *Junipers* are common. In the upper alpine region, prominent herbaceous plants are the species of *Primula*, *Polygonum*, *Gentiana*, *Cassiope*, *Meconopsis*, *Saxifraga*, *Potentilla*, *Geranium*, *Aster*, *Astragalus* etc. which form alpine meadows. At about 5000 metre altitude and above, snow perpetuates round the year and plant growth is almost nil. This altitude is called snow line or ice line.

Populations of *Draba*, *Braya*, *Cortia*, *Leontopodium* go on increasing with the increase in altitude. Species of *Ephedra*, *Juniperus*, *Barberis* are also found scattered. *Poa*, *Stipa* and *Pectuca* are common grasses of alpine zone.

(2) Eastern Himalayas

Eastern Himalayas extend from Sikkim to upper Assam, Darjeeling and NEFA. Vegetation of this region differs from that of western Himalayas. The chief differences are due to changed environmental factors as heavy monsoon rainfall, less snowfall and high temperature and humidity. This region can also be divided into *(i)* Tropical submontane zone *(ii)* Temperate or Montane zone, and *(ii)* Alpine zone (Fig. 10.3.)

(i) Tropical or Submontane Zone. This tropical subzone characterized by warm and humid conditions extends from plain up to the altitude of about 1800 m. In this zone mostly sal forests, mixed deciduous forests consisting of important plants, such as *Sterculia, Terminalia, Anthocephalus cadamba* and *Bauhinia* are common. In the savannah forests, common plants are *Albezzia procera, Bischofia, Salmelia, Dendrocalamus.* Evergreen forests of *Dillenia indica, Michelia champaca, Echinocarpus, Cinnamon* etc. are common.

(ii) Temperate or Montane Zone. It may be further divided into upper and lower zones. Lower temperate zone is the region between 1800 and 3000 metre altitudes. In the lower temperate zone, Oaks (*Quercus*), *Michelia, Pyrus, Cedrela. Eugenia, Echinocarpus* are common plants. In upper temperate zone (3000-4000 metre altitude), conifers and Rhododendrons are common, Important conifers of this region are *Picea spinulosa. Abies, Larix, Juniperus, Tsuga griffithi, Tsuga brunoniana, etc.*

(iii) Alpine Zone (from 4000 metres up to snow line). Climate is humid and extremely cold. The vegetation in the alpine zone is characterised by complete absence of trees and predominance of shrubs and meadows. Important plants of this zone are *Rhododendron* and *Juniperus.*

Eastern Himalayan vegetation is considered to be one of the richest vegetational units in the world and consists of several species of plants which are native of foreign countries, such as, China Japan, Burma, Malaya and European countries.

(3) Indus Plains

It includes part of Punjab, Rajasthan, Cutch, Delhi, a part of Gujarat. Some part of this plain is now in west Pakistan. The climate of this zone is characterised by dry hot summer, and dry cold winter. Rainfall is usually less than 70 cms, but in certain regions it is as low as 10-15 cms. The soil of a wide area, except cultivated land, is saline. Much of the land has become desert due to excessive dryness.

Vegetation is mainly bushy and thorny. *Acacia arabica, Prosopis spicigera, Salvadora, Capparis decidua* are very common plants of this region. *Salsola phoetida* and *Lunakh grass* are found mostly in saline soils. Other plants of this botanic province are *Anageissus, Eugenia,* Mango, *Dalbergia sisoo, Albizzia lebbek, zizyphus numularia etc.*

Historical evidences indicate that the area was covered by dense forest some 2000 years ago, but gradual destruction of vegetation cover either by biotic agencies or by any other agency led to the developmant of desert in this plain. *Saccharum munja, Cenchrus ciliaris, Prosopis spicigera, Acacia leucophloea, A. senegal* are the important plant species which are grown for checking the spread of desert.

(4) Gangetic Plains

This is one of the richest vegetational zones in India. This zone covers flat land of a part of Delhi, whole of U.P., Bihar, West Bengal and also a part of Orissa. Rainfall in this zone is from 50 cm to 150 cm.

A great part of the land is under cultivation. The common crop plants are wheat, barley, maize, *Sorghum* (jowar), bajra, urad, Moong (*Phaseolus mungo*), *Cajanus cajan*, til (*Sesamum indicum*), sugarcane, Pea (*Pisum sp .*), gram (*Cicer arietinum*), potato, *Brassica*, rice.

In western part of U.P. annual rainfall is from 50 cm to 110 cm. Dry deciduous and shrubby forests are common in this part. Important plants of south-western part of U.P. are *Capparis, Saccharum munja. Acacia arabica.* In the north-western part of U.P. near Himalayan foothills *Dalbergia sisoo, Acacia arabica* are most common plants.

In eastern gangetic plain, the conditions are cold and wet (rainfall, 150 cm in West Bengal). In this part, evergreen forests are common. In central part, the annual rainfall is about 100 cm to 150 cm. The vegetation consists mainly of deciduous trees. Sal trees are dominant. Other common trees are *Terminalia tomentosa, T. belerica, Acacia* species, *Bauhinia, Diospiros* (Biri ka patta or tendu), *Eugenia* sp., neem trees (margosa), *Madhuca indica* (mahua), *Cordia myxa* (Lasora), *Tamarindus, Mango* (*Mangifera indica*), *Ficus etc.*

In Bihar and Orissa hills—*Rubus—Potentialla, Fragaria* (*Rosaceae*), *Pyrus etc.* are also common. Mangrove vegetation is common in tidal region in West Bengal near Sunderbun, *Rhizophora mucronata, R. Conjugata, Sonneratia, Ceriops roxburghiana* and *Acanthus ilicifolius, Kandelia rheedii, Bruguiera gymnorhiza* are common mangrove plants in this zone.

(5) Central India

Central India covers Madhya Pradesh, part of Orissa, Gujarat and Vindhya. The areas are hilly. The average rainfall per annum may be 100-170 cm. Some places are at the altitudes of 500-700 m from the sea level. Biotic disturbances are very common in this botanical province which have led to the development of the thorny vegetation in open areas. In this region, teak (*Tectona grandis*) is very common. Other trees are (*Terminalia tomentosa, Bauhinia*, Mango, *Phyllanthus, Ficus glomerata etc.* Among common shrubs are *Mimosa rubricaulis, Desmodium, Acacia sp., Zizyphus rotundifolia* and others. Entire forest vegetation of central India may be divided into-(*i*) sal forest (*ii*) mixed deciduous forest (*iii*) thorny forest.

At Sarguja (M.P.) many species have been reported to occur. Some of them are *Pyrus, Barberis asiatica, Rubus elipticus etc.*

(6) Deccan

This region comprises whole of the southern peninsular India including Satpura and southern part of Godawari river. Average annual rainfall in this region is about 100 cm. It may be divided into the following two subdivisions :—

(*i*) Deccan plateau

(*ii*) Coromandel coast.

In Deccan plateau, teak forests containing *Diospiros, Acacia, Prosopis spicigera, Santalum album* (chandan tree) and *Cedrela toona* are common. On rocks, *Capparis*, Euphorbias, *Phyllanthus* are common. Teak, *Pterocarpus, Borassus, Foenix silvestris* are also common in this area. In Chota Nagpur plateau, important species are *Clematis natans, Barberis, Thallictrum* and also many members of Annonaceae, Rosaceae, Compositae, Araliaceae, Apocynaceae, Lauracese, Amaranthaceae, Orchidaceae. Some ferns are also common.

In Coromandel coast vegetation consists largely of some halophytic species.

(7) Western coast of Malabar

This is a small botanical province covering Cape Comorin to Gujarat and Western Ghat. This is a region of heavy rainfall. In this zone, four types of forests are common :

(*i*) Tropical forests (occur at 700 m altitude),

(*ii*) *Mixed deciduous forests* (found at the altitude up to 1600 m),

(*iii*) *Temperate evergreen forests* (occur at more than 1200 m altitude), and

(*iv*) *Mangrove vegetation.*

In tropical evergreen forest the trees are tall and they have root buttresses. Important species are *Cedrela toona, Dipterocarpus, Magnifera indica, Sterculia alata, Artocarpus hirsuta.* In the mixed deciduous forest, important plants are *Terminalia tomentosa, Terminalia peniculata, Tectona grandis, Dalbergia, Lagerstroemia lanceolata* and bamboo species, particularly *Dendrocalamus* and *Bamboosa arundinacea*. On the Nilgiri hills subtropic and temperate conditions exist. Important plants of Nilgiri vegetation are *Rubus, Rhododendron arboreum, Barberis, Thallictrum, Ranunculus, Fragaria, Potentilla.* Many other herbs alongwith many grasses are also common.

Temperate forests commonly called as "Sholas" contain *Gardenia obtusa, Michelia nilgirica. Eugenia* species are also common. In Malabar, plants belonging to family Dipterocarpaceae, Tiliaceae, Anacardiaceae, Meliaceae, Myrtaceae, Piperaceae, Orchidaceae and many ferns are common. The west coast of Malabar region receives very high rainfall. In the coastal region mangrove plants grow luxuriantly.

(8) Assam

This botanical province is very rich in vegetation and covers valley of Brahmputra, Naga hills and Manipur. This is the region of heaviest rainfall. Cherapunji is one of the rainiest places of the world where rainfall often exceeds 1000 cm. Excessive wetness and high temperature in this zone are responsible for the development of dense forests. Broad leaved tall evergreen angiosperms and some conifers are very common in the forests. Common plants occurring in this region are *Ficus, Artocarpus, Michelia champaca, Sterculia alata, Morus* species. Besides these, Bamboos, canes, climbers, and green bushes are also common. Prominent plants in the northern forest of this zone are *Alnus nepalensis, Betula, Rhododendron arboreum, Magnolia, Michelia* and *Prunus*. Sal also occurs at Garo hills. Orchids and fern species are very rich in this zone.

(9) Bay Islands of Andaman and Nicobar (India)

These bay islands represent elevated portions of submarine mountains. Climate is humid in the coastal region. In Andaman, beech forests, evergreen forests, semi-evergreen forests, deciduous forests and mangrove vegetation are of common occurrence. *Rhizophora, Mimusops, Calophyllum,* etc., are common plants in mangrove vegetation. In the interior, evergreen forests of tall trees are common. Important species of trees are *Calophyllum, Dipterocarpus, Lagerstroemia* and *Terminalia, etc.* Some part is under cultivation. The important crops are paddy and sugarcane.

QUESTIONS

1. What are phytogeographical principles? Discuss in brief the factors which affect distribution of plant species.
2. Write short notes on :
   (a) Discontinuous distribution of species
   (b) Endemism.
3. Describe the climates of India and their bearing in distribution of plant formations.
4. Describe the various forest communities of India.
5. Give an account on grassland vegetation in India.
6. Describe in brief different phytogeographic regions of India.
7. Describe the vegetation of Eastern or Western Himalayas.

11

PLANT ECOTYPES

Turesson (1920), a Swedish worker conducted a series of experiments on variations. He collected a number of plants from different parts of the country and cultivated them together in the same garden. He concluded that variations are always associated with some ecological factors and ecological races are different from other in the sense that these are intraspecific genetically fixed plants in relation to environment. The ecological factors may be climatic, edaphic or biotic type. Thus the studies brought about many changes and major revolution in plant taxonomy. On the basis of his studies Turesson proposed the following classification of plants into two :

1. Ecophenes
2. Ecotypes

Ecophenes. These are also called 'ecads' or habitat forms which are environmental induced variations. Plants having same genetic stock but showing variation in morphological characters (in shape, size, number and reproductive capacity) in response to environment. When these variants are brought to the same habitat differences disappear. So these morphological variations are not permanent because genetics is not involved. For example, *Euphorbia hirta* is prostrate cushion type when it is disturbed but it is erect in natural condition when it is not disturbed. On transplantation prostrate form becomes erect.

Plant Ecotypes

The term 'ecotype' was proposed by Turesson (1922) which he used to refer to groupings of populations or ecological races or sub-species in relation to a type of habitat or climate. Ecotypes are morphologically, physiologically and developmentally adapted to live under varying environmental conditions. Ecotype is the product of genetic response of a population to a habitat. It is a population or group of populations distinguished by morphological and/or physiological characters, interfertile with other ecotypes of the same species.

In the last two decades, many investigators have studied either only a few populations or several widely separated populations and have shown that each population was an ecotype and the term is now being widely used below the level of species. Our increasing knowledge of genecology and population differentiation has shown that an ecotype may be the ecological unit but is not an evolutionary unit. According to McMillan (1969), the concept of genetically-based variation that is habitat correlated or population differentiation or microevolution is valid, but 'ecotype' as a word has limited value in its application.

Consideration of the Turesson ecotype as a reliable ecological unit requires an assumption of environmental uniformity within climatic or altitudinal regions or habitat types. There is a strong trend among evolutionary biologists to emphasize the importance of the local environment in shaping the population. Since the unit of study is the local population, it seems most appropriate that we present our information in terms of the population, rather than to imply that a population is an ecotype. If the term "ecotype" is used equivalent to an ecological race or a taxonomic sub-species but we cannot consider the ecotype to be a basic ecological or evolutionary unit. Since the evolutionary unit is the population, the use of ecotype for the concept of genetically based variation that is habitat correlated can not contribute additional information but confusion. Ecotype is now used by botanists and ecologists to indicate almost any degree of genetic difference below the level of species. According to Philips (1971), the ecotype has been used as the word for an abstract concept of an ecosystem type.

Origin and development. The word "ecotype" was initially proposed by Turesson (1922) as the ecological unit to cover the product arising as a result of the genotypical response of an ecospecies to a particular habitat. Turesson observed the condition of various species in their natural habitats and collected seeds and plant materials which he planted in a uniform environmental condition of garden. He compared such collection in a uniform environment and raised progeny from seed to check for retention of characters and conducted breeding experiments in few cases. Later on he compiled data substantiating the existence of many hereditary forms within several distinct species.

There are two more parallel terms 'coenospecies' and 'ecospecies'. Gregor (1939) defined coenospecies and ecospecies purely on the basis of sterility fertility criteria, eliminating any specific demand for morphological, physiological or cytological differences. According to him, 'coenospecies' refers to a population which is incapable of exchanging genes with other populations while an 'ecospecies' was a population with an inherently low capacity for exchanging genes with other populations of its coenospecies.

Ecotype is still considered on the basis of morphological, physiological or ecological evidences. According to Davis and

Heywood (1963), ecotype is based on the reaction between genotype and prevailing environment. They defined 'ecotype' as a population distinguished by morphological and physiological characteristics most frequently of a quantitative nature ; interfertile with other ecotypes of the ecospecies, but prevented from freely exchanging genes by ecological biomass.

Characteristics of Ecotypes

The characteristic features of ecotypes are mentioned below :

1. Ecotypes of a species are always interfertile.

2. They retain their original features when cultivation is done in a natural habitat.

3. Ecotypes are genetically based.

4. A species with wide ecological amplitude can be distinguished on the basis of morphological and physiological characters in different habitat.

5. They occur in distinct habitat type.

6. Ecotypes are discrete entities, with clear differences separating one ecotype from another.

7. The differences are not due to plastic response to change in environment but are actually due to natural selection of locally adapted populations.

Formation or origin of new ecotypes

New ecotypes can be produced by the following methods :

1. **Hybridization**. It is produced by the natural cross between two species. For example, when *spartia stricta* is naturally crossed with *S. alterniflora*, the new hybrid *S. townsendii* results eliminating both the parents from their natural habitat to its greater adaptability.

2. **Mutation**. New hybrids may also be produced due to natural mutation and recombination. Small gene pools accumulate in an aggregated population which is better adapted to the particular habitat or environment. Due to this some new ecotypes arise by the cultivation or protected growth as it eliminates competitive selection.

3. **Chromosomal Changes**. Loss or addition of chromosome segments produces changes in genotypes followed by change in the phenotypes resulting in the formation of new ecotypes. Thus polyploidy leads to the formation of new ecotypes because polyploids hardly exhibit ecological tolerance as their parents.

Kinds of Ecotypes

According to varying environmental condition ecotypes may be of following types :

1. **Climatic Ecotypes**. Ecotypes which are produced due to varying climatic factors as light, temperature, water and wind are

called climatic ecotypes. Turesson (1930) has recorded the climatic ecotypes as *Leontodon autumnalis.*

2. **Edaphic Ecotypes.** Ecotypes which are produced due to differences in edaphic or soil factors as soil moisture, excess or deficiency of nutrients, change of soil etc. are said to be edaphic ecotypes. Misra and Rao (1948) have studied *Lindenbergia polyantha* and Ramkrishnan (1961) has studied *Euphorbia thymifolia* as edaphic ecotypes.

3. **Climatic-Edaphic Ecotypes.** Sometimes ecotypes produced due to the influence of both climatic and edaphic factors are called climatic-edaphic ecotypes. Pandey and Jayan (1970) have studied *Cenchrus ciliaris* as Climatic-Edaphic Ecotypes.

4. **Altitudinal and Latitudinal Ecotypes.** The ecotypes which are produced due to change in altitude and latitude. Such ecotypes are found in *Cassia tora, Anagallis arvensis, Pinus* and other gymnosperms.

5. **Physiological Ecotypes.** The ecotypes which are produced due to physiological changes as photoperiod, water absorption, nutrient uptake etc. Example *Boutelona curtipendula.* In this plant there are two photoperiodic ecotypes -- short day and long day, although they are morphologically alike.

Some Indian Examples of Ecotypes

1. Misra and Rao (1948) studied autecology of *Lindenbergia polyantha* and *Lindenbergia urtaecifolia.* Both species are ecotypes of single species *L. polyantha* but earlier plant taxonomists considered as different plant species, due to marked differences in flower size and colour. *L. polyantha* grows in calcium rich soil but *L. urtaecifolia* grows on normal soil.

2. Ramkrishnan (1959) studied two forms (ecotypes) of *Euphorbia thymifolia*—(*i*) Red form—which is facultative calcicol (grows on soil rich in calcium or ordinary soil) (*ii*) Green form is obligate calcicol which grows on soil poor in calcium. Both forms cannot interbreed with each other.

3. **Euphorbia hirta** has two ecotypes (Ramkrishnan, (1959, 60)

Ecotype I

Ecotype II

Ecotype I is erect, prostrate which grows on moist habitat.

Ecotype II has two forms—one is prostrate growing on dry lands and another is prostrate cushion-like growing on foot paths. There are two ecads of the same ecotype.

4. **Cassia tora** species exhibits ecotypes due to latitudinal differences (Singh, 1966).

5. **Xanthium strumarium** shows physiological/climatic ecotypes which is due to photo and thermoperiods (Kaul, 1959).

Delimitation of Ecotypes

Ecotypes are not always based on morphological characters. Sometimes single ecotype has several ecophenes which depends upon the habitats. Nowadays following techniques have been applied to differentiate ecotypes ;

(*i*) **Morphological features**. In this case morphological or physiological features of several individuals are studied at random from each of different populations of a species and one or few characters are considered and the results obtained are shown in the graph. Unimodal curve shows homogenous population, bimodal, trimodal or multimodal curves show two, three and many ecotypes in the population respectively.

(*ii*) **Anderson's Scatter Diagrams**. This was devised by Anderson (1940) to delimit ecotypes. For this some measurable characters are taken into consideration. One type of character (for example, leaf length) is plotted on one side of the graph and other character (for example, leaf breadth) is plotted on another side. In this way large number of characters are taken from different localities.

(*iii*) **Cytological behaviour**. In this case different karyotypes and their behaviour are observed. The differences in cytological behaviour show the existence of distinct ecotypes.

(*iv*) **Transplantation Experiment**. In this experiment plants from all the different localities under uniform environmental condition are taken and their morphophysiological characters are compared with plants growing in natural habitats. If the characteristic features are not changed in the neutral area, the existence of particular ecotypes is confirmed.

(*v*) **Breeding Experiments**. In this case crossing is brought about between different forms of variable nature followed by self-fertilization to determine the characteristic features of variable forms. If the characteristic features show the persistence in the offsprings, the presence of distinct ecotypes can be proved.

Significance of Ecotypes

1. Cultivation of economically important plants has been made possible in different habitats.

2. New evolved species are adapted in climatically and edaphically different places.

3. Ecotypes help the species to extend and adapt in wide ecological range.

4. Morphological variations can be marked in the species growing on varying habitats which lead to evolution.

QUESTIONS

1. What is ecotype ? Describe the origin and development of ecotype.
2. What are characteristic features of ecotype ? How new ecotype is evolved ?
3. What are different types of ecotype ? Describe with suitable examples. Give some Indian examples of ecotypes.
4. What is the difference between ecotypes and ecophenes ? What is the significance of ecotypes ?

12

PLANT INDICATORS

It is a well known fact that heredity determines the characters of plants. On the other hand, environment influences the plant growth. Thus heredity and environment both are equally important in the formation of phenotypic characters. Heredity performs its action through environment. Every organism is a product of environmental conditions under which it grows which determine the environment. Plants grow successfully in favourable conditions of environment. Species differ in their environmental requirements but establish themselves where conditions are favourable. The characters and behaviour of a plant are thus indicator of the combined effects of all factors prevailing in a habitat. A plant species or plant community acts as a measure of environmental conditions, it is referred to as *biological indicator* or *bioindicator* or *phytoindicator*. In other words, plants which can be used as indicators of specific habitat are called plant indicators.

The knowledge of relationship between plants and ecological factors can be used as an indicator of environment. Many plants are used as indicators of environment. In a plant community some plants are dominant which are found in abundance. These plants are important indicators because they get full impact of habitat. It has been seen, in general, that plant communities are better indicators than individual plants. Individual plants or plant communities are used to determine the types of soil and other conditions of the environment. Sometimes these also indicate past or future conditions of the environment.

The knowledge of plant indicators can be helpful to determine local soil, thus it can be decided which crops are cultivated in a particular soil and which should be left for pasture or other purposes. Plant indicators are also used to determine optimum use of land resources for forest, pasture, agricultural crops. Many plants indicate the presence of particular mineral or metal. So the presence of precious metal can be detected by the growth of the specific plant in an area.

Characteristic features of plant indicators

The characteristic features of plant indicators are given below :

1. On the basis of distribution the indicators may be 'steno' species or 'eury' species. The 'steno' is used to indicate narrow limits of tolerance and 'eury' is used to indicate wide limits of tolerance. A plant may be of wide limits of tolerance for certain conditions and narrow limits of tolerance for other conditions. For example, a plant may be of wide limits of tolerance for heat but of narrow limits of tolerance for water. Plants of wide limits of tolerance of heat are called *eurythermal* and narrow limits of tolerance for water are called *stenohydric.*

2. Plants of large species are better indicator than the plants of small species.

3. Before relying on a single species or group of species as indicators, there should be abundant field evidence.

4. Numerical relationships between species, population, and whole communities often provide more reliable indicators than single species.

Different types of Plant Indicators

Different types of plant indicators have different role in different aspects which are described below :

1. **Plant indicators for agriculture.** Many plant indicators decide whether soil is suitable for agriculture or not. The growth of a particular crop plant is seen under different environmental conditions and if growth is satisfactory the soil is considered to be suitable for agriculture. For example, growth of the short grasses indicates that water is less in the soil. A natural growth of tall and short grasses indicates that soil is fertile and is also suitable for agriculture. Dhawan and Nanda (1949) have recorded following plant indicators for different types of soils :

Plant indicators	*Characteristic of soil*
Salvadora oleoides	High Calcium and Boron, good soil suitable for crop plants
Zizyphus nummularia	Good soil for agriculture
Prosopis cineraria	Good soil for crop plants provided irrigation is there
Peganum harmala	Soil is rich in Nitrogen and salts and good for agriculture
Butea monosperma	Heavy alkaline
Capparis decidua	Alkaline soil

Plant indicators for overgrazing. Many plants are overgrazed which result in modification of grassland. It has been seen that grasses are removed by overgrazing while others are disturbed and forage production is considerably reduced. Some plants which are vigorous are undisturbed, remain viable and become distinct from rest of the plants. Some plants show characteristic indication of overgrazing which can be recognised. The predominance of annual weeds and short-lived impalatable perennials indicate severe grazing. Such plants are *Polygonum*, *Chenopodium*, *Lepidium* and *Verbena*. Some plants are less pronounced and show poor or no overgrazing. Examples of these plants are *Opuntia*, *Grindelia*, *Vernonia* etc.

Plant indicators of forest. Some plants indicate the characteristic types of forest and can grow in an area which is not disturbed. *Narenga porphyrocoma* is a grass which binds the soil. In such soil sal (*shorea robusta*) can be cultivated. *Viola* species in western Himalayas is a suitable indicator for plantation of *cedrus deodara* and *Pinus wallichiana*. If we know that a particular forest grows better in certain area of specific soil the productivity can be increased. For example, *Quercus stellata* and *Q. mariandica* grow on upland, lowland or on sterile sandy soil.

Sometimes forest is destroyed due to fire, overgrazing and other environmental factors and area is left to reach up to climax. In this area subdominant species get favourable chances for growth and survival. This indicates the future plants to come and establish.

Plant indicators for humus. Some plants act as humus indicators. *Monotropa*, *Neottia* and mushrooms indicate the presence of humus in soil. *Strobilanthes* and *Impatiens* indicate the presence of high humus or litter which prevents regeneration of tree species.

Plant indicators for moisture. Plants prefer to grow in arid area which indicate the poor or very low moisture content in the soil. *Saccharum munja*, *Acacia nilotica*, *Calotropis*, *Agave*, *Opuntia*, *Argemone* are such plants. Some plants grow in low soil moisture as *Citrullus colocynthis*. *Eucalyptus* lowers the water table. *Echinops echinatus*, *Cassia auriculata* are found in deep water table. *Typha*, *Phragmites* and *Vetiveria* grow in water-logged soil. Growth of *Typha*, *Phragmites*, *Juncus* and *Carex* indicates the swampy condition. Mangrove vegetation and *Polygonum* are found in saline water-logged soil.

Plant indicators for soil types. Many plants indicate the characteristic soil. For example, *Casuarina equisetifolia*, *Ipomoea pes-caprae*, *Citrullus colocynthis*, *Calliganum polygonoides*, *Lycium barbarum* and *Panicum* grow in sandy soil. *Saccharum munja* prefer to grow in sandy loams. *Imperata cylindrica* and *vetiveria zizanioides* grow on clayey soils. Cotton prefers to grow in black soil.

Plant indicators for soil reaction. Many plants indicate the soil whether it is acidic or bask. For example, *Rumex acetosa*, *Rhododendron*, *Polytrichum* and *Sphagnum* indicate acidic soils. Many forest trees as *Shorea robusta*, *Pinus roxburghii* are calcium loving (calcifuges). *Tectona grandis* (Teak), *Cupressus torulosa*, *Ixora* *parviflora* and *Taxus baccata* are calcicoles. Some mosses *e.g. Tartella* and *Neckera* grow on lime stones. Halophytes such as *Suaeda fruticosa, Tamarix articulata, Salicornea, Chenopodium, Salsola foetida* grow in salty soil.

Plant indicators for minerals. Many plants prefer to grow in the presence of characteristic minerals. These plants are called *metallocolus* or *metallophytes.*

Following plants grow in the presence of specific metals :

(*i*) *Diamond. Vallozia candida* grows in presence of diamond in Brazil.

(*ii*) *Gold. Equisetum arvense, Lonicera, confùse, Papaver libonoticum, Alpinia speciosa, Thuja* species grow in presence of gold minerals.

(*iii*) *Silver. Eriogonium ovalifolium* grows in presence of silver minerals in U.S.A.

(*iv*) *Mercury. Stellaria setacea* grows in Spain in presence of Mercury.

(*v*) *Uranium. Astragalus* species grows in USA in presence of Uranium.

(*vi*) *Selanium. Astragalus* species, *Neptunia amplexicaulis, Stanleya pinnata, Onopsis condensator* etc. grow in presence of *Selanium.*

(*vii*) *Copper. Viscaria alpina* in Norway, *Gymnocolea acutiloba* in America, *Gypsophila patrini* in USSR grow in presence of Copper.

(*viii*) *Zinc. Viola calaminara, V. lutea* in Europe grow in presence of Zinc minerals.

(*ix*) *Boron. Salsola nitrata, Eurotia cerutoides* grow in presence of Boron.

(*x*) *Cobalt. Silene cobalticola* in Congo and *Nyssa sylvatica* grow in America in presence of Cobalt.

(*xi*) *Nickel. Lychnis alpina* grows in Sweden in presence of Nickel.

(*xii*) *Sulphur. Allium, Arabis Oenothera, Atriplex* grow in presence of sulphur minerals.

(*xiii*) *Lithium. Lycium, Juncus, Thalictrum* grow in presence of Lithium.

(*xiv*) *Iron. Damara ovata, Dacrydium caledonicum* grow in Scotland in presence of iron minerals.

(*xv*) *Aluminium. Flex aquifolium* grows in Italy in presence of Aluminium.

Besides above, the mineral content in a plant tissue can be employed in biogeochemical prospecting. Lyon and Brooks (1969) have found *Olearia rani* to be valuable for the molybdenum.

Similarly silver has been discovered in certain localities in leaves of plants. Sulphate content of leaf can be directly related to SO_2 concentration in air. Farrar (1977) has seen sulphur content in pine needles to the atmospheric SO_2 concentration. Fluoride content in *Sorghum vulgare* leaves indicates the distance up to which air pollution by a fluoride source can fallout and this distance may be up to 4 km. In some cases higher copper content may be due to high-tension copper wires. Mercury concentration in *Festuca rubra* grass may be due to chloroalkali set-up and lead in leaves may be increased due to automobile exhaust.

Plant indicators for heavy metals. Soils having ore-bearing rock contain heavy metal ions especially Zn, Pb, Ni, Co, Cr, Cu, Mn, Mg, Cd, Se etc. Out of these Mn, Mg, Cd and Se are toxic to most plants. Heavy-metal contamination also occurs in industrial area due to emission of metal dust and the presence of Cd, Hg and other metal salts in bodies of water along roads. Most plants are sensitive to heavy metals. Opening of stomata is affected, photosynthesis is decreased, respiration is disturbed and growth is slowed. Many of these heavy metals are deposited in their cell walls of roots and leaves. Some of the heavy-metal plants (metallophytes) can be used as indicator plants for one deposits near the surface, and are suitable for planting in mining and industrial areas. *Cardaminopsis halleri*, *Silene vulgaris*, *Agrostis tenuis*, *Minuartia verna*, *Eichhornia crasspes*, *Astragalus racemosus*, *Minuartia verna*, *Thlaspi alpestre* are metallophytes of heavy-metals.

Plant indicators for saline habitat. Some plants grow and survive in habitats with a high salt content. They are called salt plants or halophytes. Such plants are commonly found near sea shores where mesophytes and hydrophytes cannot thrive well. Although these plants grow in areas which are well saturated with water yet they cannot avail of the water due to high concentration of salts in the soil. These plants either evade salinity or avoid salinity or resist it and few tolerate salinity. Salty soil is due to presence of Sodium chloride, Calcium sulphate, Sodium carbonate, Potassium chloride. Important plants growing in such habitat are *Chaenopodium album*, *Suaeda fructicosa*, *Haloxylon salicorneum*, *Salsola foestrida*, *Tamarix articulata*, *Rhizophora mucronata*, *Avicennia alba*, *Acanthus ilicifolius*.

Salt resistance is the ability of a plant to withstand the presence of excess salts without serious damage. Resistance depends on species, tissue type, vitality, ionic ratio and increased ion concentration. Resistant plants can survive in 4—8% NaCl, whereas salt-sensitive plants are destroyed in 1—5% NaCl. Salt resistant plants are *Betula papyrifera*, *Elaeagnus angustifolia*, *Fraxinus excelstor*, *Populus alba*, *P. canadensis*, *Potentilla fruticosa*, *Rosa rugosa*, *Salix alba*, *Ulmus americana*, *Juniperus chinensis*, *Pinus nigra* etc.

Plant indicators for Pollution. The use of vegetation, as biological indicator of environmental pollution has a long history dating back to the miners canary to the recognition about 100 years ago of the effect of SO_2 on vegetation surrounding smelters (Devenport and Margis, 1954). Knowledge of specific resistance to pollutant is of practical significance when plants grow in industrial or thick populated areas. Species differ in sensitivity of pollutants. In general plants are more sensitive to pollutants than human, therefore, plants can be used for the bioindication of environmental pollution. Sensitive species can serve as indicators and resistant species as accumulators and such plants collect large amount of pollutant without damage. Mosses, lichens and some fungi are more sensitive to SO_2 and halides. Even 1% of SO_2 concentration is harmful to higher plants. Lichens do not survive in areas that receive more SO_2 exposure.

Many chemicals, fertilizers, pesticides and high consumption of fossil fuels release toxic substances into the environment that are taken up by the plants from air, water and soil. Atmospheric pollutants are dangerous to plants particularly SO_2, halides (HF, HCl), Ozone and Peroxi-acetyl-nitrate (PAN) produced from automobiles, industrial fumes and strong radiation. Harmful substances that reach to plants through the air are : SO_2, nitrogen oxides, ammonia, hydrocarbons, dust, smoke. Plants growing in water are severly affected by toxic chemicals in sewage (cyanide, chlorine, hypochlorate, phenol, benzol derivatives and heavy-metal compounds).

The effects of different kinds of pollution can be determined by the product of their concentration and the period of exposure. Under exposure to high concentration plants suffer acute injury, with externally visible symptoms such as chlorosis, discolouration, necrosis and death of entire plant. Besides morphological changes, chemical, biochemical, physiological and fine structural changes have occurred in plants.

Pollution damage can be recognised by accumulation of the toxic material in the plant, changes in pH, reduced or increased activity of certain enzymes, increase in compounds with SH groups and phenols, lowered ascorbic acid level in the leaves, depression of photosynthesis, stimulation of respiration, low dry matter production, changes in permeability, disturbances in water balance, reduced fertility under prolonged exposure. The disturbances of metabolism develop into chronic injury with irreversible consequences. Plants show reduced productivity and yield and quality is also lowered. Besides above, the structure of wood is changed, branches dry out and gradually the trees die. The symptoms of pollution infected plants are varied and unspecific. A particular pollutant -affects different plants in very different ways and a particular symptom can be produced by a variety of substances. The influence of external factors (pollutants) on plants depends on the species, stage of development and the organ or tissue involved. Morphological alteration of a plant and floristic composition of a plant community are commonly used to indicate changes in the environment. (According to Van Haut and Stratmann (1970), visible plant symptoms are most commonly used to indicate the responses of plants to pollutants.

Jacobson and Hill (1970) have studied the effect of common pollutant on plants. It is possible that any part of a plant body, if it responds specifically or characteristically to any pollutant, can be used for its indication. Goldstein (1974) emphasized that the number and kind of biological indicators can be subdivided in order of decreasing biological complexity, such as organism, organ, tissue, cell, cell-free preparation and enzymatic studies. M.U. Beg (1980) from Industrial Toxicology Research Centre, Lucknow has reported the responses of pollutants as a biological indicator taking several parameters into consideration.

Attempts have been made to use certain structures and functions of plants, such as seed germination, growth of plant, development of lateral branches, expansion and colour changes in leaf, flower and fruit formation, decolorisation of flower, loss of physiological control, mineral composition, chemical constituents of cells, enzymatic activity and pollen germination, as indicator of pollution stresses. Important aspects in response to pollution are summarised below.

Germination. Seed germination has been used by many workers to monitor pollution responses. Several growth parameters such as percentage of germination, seedling survival, seedling height, cotyledonary expansion and fresh and dry weight have been taken as criteria to assess plant response to a specific pollutant. *Phaseolus vulgaris* has been grown in smoke-free and smoke-affected regions by Sorauer (1899). The toxic effect of thiosulphate has been indicated as germination inhibition in many plants. Houstan and Dochinger (1977) have evaluated in relation to pollution by sulphur dioxide and ozone. The effect of Lead, Cadmium, NO and CO_2 has been studied in many plants. Besides seeds germination, pollen germination has been used to indicate pollution in *Nicotiana sylvestris*.

Morphological changes. Prof. D.N. Rao (1977) has studied the response of pollution in a number of plants as indicator. *Polygonum*, *Rheum*, *Vicia*, *Phaseolus*, and *Capsella* have been observed as pollution indicators. According to Brandt (1974), large number of plant species are capable of detecting species contaminants. Generally, the plants response to pollutants in characteristic rather than specific. Efforts have been made to develop certain plant strains which can specifically be used as indicator for a particular pollutant. Stunting of corn, sweet potato and rye has been reported due to high toxicity. Reduction in root length, shoot length, number of tillers, leaves, ears and grains in wheat has been reported under conditions of cement dust pollution. Similarly plant height, number of leaves and boll per plant reduce in cotton exposed to particulate pollution. Inhibition of lateral growth of forest trees is caused by lime-stone dust. Pine trees do not flourish in SO_2 polluted areas. It has been noticed that leaf is the most sensitive to pollution. The pollution indicator value of leaf has been exploited by many workers in response to a variety of conditions. Leaf injury is a characteristic symptom to various pollutants. The characteristic symptoms of leaf include pigmentation, chlorosis, yellowing, necrosis etc. The leaves of dicotyledons generally exhibit spotted markings between the veins while monocotyledons usually show necrotic streaks between parallel veins. Injury may also occur along the margin and tips. Symptoms produced by ozone, oxides of nitrogen and chlorine are almost similar. Reduced expansion of cotyledonary leaves in response to pollution has been observed in several cases. Necrotic lesions and reduced net primary productivity in different concentration of SO_2 has been reported by L.C. Mishra (1980).

Recently epidermal morphology has been studied as indicator in response to different pollutants specially SO_2. Cuticle and epidermis damage can be used to indicate air pollution. Dry weight of leaf, decrease in leaf thickness, cell size, loss of leaves and early senescense may be due to smoke and SO_2 pollution. Yunus and Ahmad (1980) have observed that leaves of polluted area of cement factory showed higher stomatal and trichome densities, smaller epidermal cell and trichone sizes as compared to leaves obtained from unpolluted atmosphere.

Pollution indicator plants and their characteristic features
(Legfar, 1971)

Pollutant	*Characteristic features*	*Plant indicator*
Ozone	Red or brown spots or streaks on the upper surface of the leaves, in presence of more pollution leaves margins are curled or form, wilting of apical part of pine needle occurs.	*Salvia, Dahlia, Pinus*
SO_2	Light spots on the margin or near the veins, killing of tissues.	*Ficus, Xenia, Pinus*
Hydrogen Fluoride	Tissues of apical part and margin of leaves are destroyed.	*Gladiolus, Pinus*
Feroxi-acetyl nitrate	Destruction of chlorophyll of leaves and cells of lower surface are killed.	*Pitunia, Salvia, Chrysanthemum, Primrose*

Biochemical and physiological changes

Chemical composition of leaf has widely been used to indicate environmental conditions. Among the biochemical estimations, the most important parameter is pigment analysis. Chlorophylls *a* and *b* have been measured as index of response of different types of pollution. In *Cassia, Cynodan* 50% reduction of chlorophyll has been observed while *Saccharum* is least affected. Chemical estimation like proteins, aminoacids, soluble sugars, sucrose, starch, reducing sugars, vit. C, riboflavin, thiamine and carbohydrate are used to indicate foliar sensitivity to air pollution.

Physiological activity as opening of stomata, and rate of photosynthesis can also be used as indicator of pollution. Photosynthesis as a parameter has been used for mixed exposure of SO_2, NO_2 and dust.

Enzymatic parameters are also used to indicate the presence of particular pollutant. Peroxidase was found to be the most sensitive indicator of pollutants in the absence of visible injury. Kellar (1974) and Jager (1975) have reported a differential response in enzymes in areas affected by fluoride, automobile pollution and SO_2. Thus on the basis of enzyme activity, the susceptible species of plants can be identified. Many workers have reported that enzymatic activity has been related to air pollution. Other common enzymatic parameters used are ribulose diphosphate carboxylase, glutamate-pyruvate transaminase, glutamate-oxaloacetate transaminase and peroxidase for SO_2 pollution.

QUESTIONS

1. **What are plant indicators ? How indicators can be used in different conditions ?**
2. **Write short notes on :**
   - **(*a*) Biological indicators**
   - **(*b*) Pollution indicators**
   - **(*c*) Plant indicators for agriculture**
3. **Describe different kinds of plant indicators with suitable examples.**

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13

ENVIRONMENTAL POLLUTION

Today millions of people are without the basic human needs of food, cloth, shelter, health, education and employment. This is not only due to overpopulation alone but also due to environmental consequences. The loss of forest, fertile soil, productivity and energy crisis has created many problems. The pollution created by industry, technology and over-consumption of the affluent society lead to the rapid depletion of basic natural resources. Many human problems are also due to mismanagement of environment created by man himself.

Environmental implications due to pollution are in various aspects. These produce serious problem to maintain its existence, protection, survival and for the improvement of general standard. The basic needs of human beings have disturbed our natural resources and finally led to a situation which has threatened to be disastrous. In the recent years everyone has started thinking the problem of over-population and its consequences which is primarily concerned with the environmental pollution and every effort should be made to focus our attention to save mankind from self-destruction and further steps should be taken at national and international level so that the consequences may not become worse.

The ecological state of biosphere is becoming more and more imbalanced day by day due to technical and industrial advancements as well as population explosion. Vast changes are taking place in the environment due to interaction between human society and environment itself. Man is exploiting the natural resources for its own interest and many such instances are there which clearly indicate that man has disturbed the natural balance for the sake of small benefits and has changed the environment of many places to such an extent that they are not fit for inhabitation by living beings.

The environmental science is concerned with the study of all the systems of air, land, water, energy and life that surround us. Environmental problems are so diverse and diffused that virtually every activity of civilization interacts with the environment. The addition of extraneous materials or energy in a particular environment in concentrations greater than normal renders the environment partially or wholly unfavourable for human life. This is referred to as environmental pollution. "Environmental pollution is the unfavourable alternation of our surroundings, wholly or largely as byproducts of man's action through direct or indirect effects of changes in energy patterns, radiation levels, chemical and physical constitutions and abundance of organisms." These changes may effect man directly or through his supplies of water and of agricultural and other biological products, his physical objects or possessions, or his opportunities for recreation and appreciation nature.

—from U.S. Products Science Advisory Committee. Environmental Pollution Panel (1965)

Pollution and contamination are two terms sometimes used interchangeably. Contamination is the presence of harmful substances or organisms that may cause disease or discomfort to human being. Polluted material need not necessarily be contaminated. Dependent as he is on air, water and food from environment, man is the main culprit in polluting these natural resources to the point of no return.

Pollution is defined as the addition of (extraneous) constituents to water, air or land which adversely affect the natural quality of the environment. In some cases, it may involve the removal, rather than addition, of constituents from the environment. A pollutant is a substance which may alter environmental constituent or causes a pollution. A pollutant can also be defined as constituent in the wrong amount at the wrong place or at the wrong time. For example, Nitrogen, Phosphorus and Potassium are extensively used in agriculture to increase crop yields but sometimes they cause pollution in lakes and rivers by promoting algal growth.

The natural sources of pollution are, no doubt, more important on a global scale, man generated pollutants may be more important in urban and industrial areas where the adverse effects of pollution are most severe. There is accumulating evidence that many types of pollutants can be distributed over the whole earth in relatively short period of time. Radioactive fallout from atmospheric nuclear explosion test is detectable throughout the world within a few days or weeks ; not even the polar regions are immune from fall-out. Comforts giving automobile are polluting the atmosphere with oxides of C, N, and other noxious gases. Coal, diesel oil and other fossil fuels are emitting suffocating SO_2, and choking our lives. Synthetic chemicals like plastic are adding to the problem of solid waste disposal, while now detergents that cannot be decomposed by microorganisms are making the natural rivers and streams polluted bubble box. Some other effects of environmental pollution are problem of health, soil erosion, sanitation, water supply, energy crisis, population and depletion of natural resources.

The law of conservation of mass or material equally applies to the pollutants and while one cannot destroy them, they may be changed from one state to another or from one compound to another The presence of small amount of pollutants may have profound influence on human health even when the level of air pollutants is so low that they cannot be detected except with special instruments. Some pollutants may harm living creatures exposed for long periods of time.

As regards the nature of pollutants, the problem of pollution can be divided into following categories :—

1. Pollution caused by solid wastes
2. Pollution caused by liquid wastes
3. Pollution caused by gaseous wastes
4. Pollution caused by wastes without weight.

1. Pollution Caused by Solid Wastes. A number of materials constitute solid wastes which are either domestic or industrial. Urban people dispose garbage and other solids to some public places or in open dumps.

The solid wastes include the following pollutants :—

(*i*) *Garbage*, such as, wastes from. kitchen, slaughter houses cannings and freezing industries.

(*ii*) *Rubbish*. Combustible wastes, such as, leaves, grasses plants from the garden and non-combustible wastes such as bottles, crockery and plastic materials.

(*iii*) Ashes.

(*iv*) Large wastes formed due to demolition and construction processes, as for example bricks, plastic, furniture, etc.

(*v*) Dead animals wastes.

(*vi*) Sludge, settled solid components of sewage wastes.

(*vii*) Industrial solid wastes as for example, chemical, paints, sand, etc.

(*viii*) Mining wastes, such as, wastes from coal mine.

(*ix*) Agricultural wastes, such as farm animal waste, manure, crop residue, pesticides, insecticides and so on.

The problem of solid domestic wastes whether it is garbage, litter or rubbish cannot be underestimated. In advanced countries it is estimated that an average city dweller produces more than half a ton of garbage per year. Fortunately, many natural organic compounds are degraded by bacteria and other microbes and some are oxidised and dissociated automatically.

2. Pollution Caused by Liquid Wastes. Major portion of water on the surface of earth is not in a form that can be used for domestic purposes by man since it is saline. Man obtains fresh water from the well known hydrologic cycle. Surface runoff gathers minerals and organic impurities as it moves down to the sea. Under normal condition, river takes care of many pollutant substances that enter its body. Green plants and algae take up CO_2 from water and in presence of sunlight synthesize carbohydrates and O_2 is produced by splitting of water molecules. Dissolved materials are taken up by bacteria and plants. Animals take up O_2 and give up CO_2 and other compounds which are used by the plants. This is ecological balance in a natural stream. If some organic matters that can be food materials for bacteria enter water course then bacteria oxidise these materials and in that process take up O_2 from water. If the process of re-oxygenation is slower than the process of de oxygenation then river will be without the life sustaining dissolved oxygen and aquatic animals and plants die and under anaerobic condition foul smelling hydrogen sulphide and other products are formed. The river can be termed dead in that it cannot sustain normal aquatic life.

Sewage. The important source of organic pollutants is sewage which contains faecal matter, urine, and kitchen washings and some soil washings. Sewage contains large number of bacteria, both pathogenic and harmless. The strength of an organic waste material of sewage is measured in terms of demand for dissolved oxygen required in oxidation of organic matter by micro-organisms. This value is expressed in terms of m gm of O_2 per litre of waste. Since biological reaction is dependent on time and temperature, this O_2 demand (called biochemical O_2 demand or B.O.D.) is given for 5 days at 20°C. If the volume of B.O.D. is below 1500 mg per litre, the sewage is termed *weak waste*, if it is below 4000 mg per litre it is *medium* and above this value it is termed *strong waste*.

Domestic sewage in small quantities rarely gives trouble. However, if liquid industrial water wastes enter the river along with acid or alkali, poisonous substances like cyanides etc., the aquatic life in the river is affected and self-purification system of water is impaired. Surface run off from agricultural fields can carry nitrogen and phosphate fertilizers that increase the aquatic plant life and later undergo decomposition adding to the organic loading of the stream. Pesticides, herbicides that enter waters may kill some organisms or accumulate in the fish which, when consumed by man, pass on the chemicals giving rise to cumulative poisoning.

3. **Pollution from gaseous wastes**. The gaseous wastes—most dangerous to people—are someones that threaten the life of animals and plants. Carbon monoxide, SO_2, NO_2 (nitrogen dioxide), ozone and the so called "Smog gases" made up of complex mixtures of hydrocarbons are common gaseous pollutants. These are the gases generally found in industrial cities.

Carbon monoxide, which is a product of incomplete combustion, is deadly poisonous at high concentration. It has high affinity for haemoglobin in the blood and prevents that from transporting oxygen from the lungs to the tissue of the body. Fortunately most of the time the amount of CO in the open air is too low to do much damage to human health.

Hydrogen sulphide is another deadly gas when it occurs in large concentrations, which is rare. Of the common gaseous pollutants, SO_2 is regarded as one of the most dangerous gas to human health. It attacks the respiratory tracts and interferes in the breathing mechanism. Concentrations above 1 ppm (part per million) can begin to affect people.

Nitrogen dioxide gas in sufficient quantities may attack the lungs and cause eye irritation. Some hydrocarbons and nitrogen dioxide under the influence of sunlight produce complex substances affecting the eyes and mucous membrane. Smog is the result of fog and the photochemical oxidation products of hydrocarbons and other organic compounds released from automobile exhaust.

4. **Pollution from wastes without weight**. The fourth kind of pollution termed as "wastes without weight" can also be called pollution by energy waste. Certain types of pollution cannot be seen and these are included in this group. Wastes without weight include the following :—

(*a*) Radioactive substances

(*b*) Heat

(*c*) Noise.

(*a*) *Radioactive substances.* The amount of radioactivity in this atomic age has increased in the environment many fold as compared to Thirties and Forties. According to one authority, man may be already having radioactive cesium in his muscles, radioactive strontium in his bones and radioactive iodine in his thyroid indicating the extent of radioactive pollution. Although every precaution is taken in the functioning and maintenance of nuclear reactor, it has been shown that minute, yet measurable amount of radioactive waste material escapes out into the environment. From the mining operation of uranium to the use and final disposal of wastes in the reactors, waste materials continuously escape out. Besides, emission from nuclear installation, there is worldwide fallout of radioactive substances from atomic bomb test. This kind of radioactive pollution caused alarm in the late Fifties and Sixties leading to a moratorium on surface and aerial tests explosions by the super powers. China and France incidentally continue to make occasional tests.

The underground storage of radioactive material in concrete or steel container still does not ensure complete safety. Radioactivity cannot be destroyed and hence it has cumulative effect. The minute radioactive atoms, molecules or ions (in water to which they may have leaked out) pass on to aquatic organisms and since they are part of food chain, the radioactivity goes on accumulating in the higher organisms. In a survey of Columbia river, into which cooling water of plutonium producing reactors was dumped, it was estimated that compared to the radioactivity of river water the microscopic plants and animals had one thousand time more radioactivity, fly larvae had 35,000 times radioactivity, while the eggs of ducks which feed on the larvae etc., had 40,000 times and some birds almost 75,000 times as much radioactivity as the water.

(*b*) *Heat.* A large quantity of waste heat energy by way of hot liquid stream or hot gases released by industries, automobiles etc., dissipates in atmosphere and water.

(*c*) *Noise.* Noise is unwanted sound. It has come to be regarded as an important pollutant of the environment. The sources of noise for the general public are the machine in the industry, traffic noise due to trucks and cars as well as due to the indiscriminate use of transistors, radios and public address systems. Processions, Public broadcasting of film, music of high pitch on festive occasions are the noise that pollute environment. Noise produced from the aircraft, especially the supersonic jet is harmful.

DIFFERENT TYPES OF POLLUTION AND THEIR EFFECTS

Water Pollution

Many of the wastes of human society are disposed of in the bodies of water, rivers, lakes, oceans and some of the wastes disposed of in air or land may eventually enter the bodies of the waters. When the human population is concentrated too much the waterways are unable to handle the quantities of materials that are turned into them and consequently they become polluted with unhappy results. Today there is growing concern about the pollution of our lakes and rivers. Marine pollution is the matter of international concern from the point of view of conservation of living resources. There can be no doubt that there has been a serious decline in environmental quality and production in estuarine and shallow coastal waters as a result of pollution. The results of water pollution are evident whether measured by harms to living resources or hazards to human health or reduction of immunities·

Water pollutants and their effects. Contamination of the industrial wastes which come in the water is most dangerous. The sewage of big cities is often drained into rivers. This sewage promotes the growth of phytoplanktons. This excessive growth depletes the oxygen in the water. This reduction of oxygen and the presence of poisonous wastes affect the fish population. Besides this, rivers, lakes and ponds are also used directly by people for bathing and washing, This contaminates the water with the germs of various diseases like cholera, dysentery and hepatitis.

The effluents produce physical, chemical and biological changes in water. Some pollutants produce only a temporary effect on water whereas others have a long standing effect. There are several types of physical and chemical effect produced by pollutants. These are : (1) addition of poisonous substances; (2) addition of suspended particles; (3) addition of non-toxic salts; (4) water deoxygenation and (5) Heating of water. Some of the important water pollutants and their effects are as follows :

1. **Sewage and other oxygen demanding wastes.** These are largely organic materials that can be oxidised by micro-organisms to CO_2 and water. When the amount of sewage discharged is

relatively small the river will not become badly polluted- So the biological degradation will soon remove most of the wastes. However, medium and strong sewage as well as other O_2 demandiug wastes from industry and agriculture can lead to depletion of dissolved O_2 in water, Septic conditions are siad to prevail when the dissolved O_2 is very low.

Sewage and other C_2 demanding wastes are classified as water pollutants because of the following reasons :—

(*i*) their degradation leads to O_2 depletion which affects or even kills fish and other aquatic life ;

(*ii*) they produce foul odours and undesired colours ;

(*iii*) they may lead to scum and sludge that render water unfit for recreational use.

2. **Infective agents**. Waste water from municipalities, sanitoria, tanning and slaughtering plants and boats discharged in the rivers, streams, lakes, etc. may be a potential source of infectve bacteria and other microbes which cause diseases in man and other animals, as for example, cholera, typhoid and many skin diseases are transmissible through polluted water.

3. **Plant nutrients**. Surface runoff from agricultural fields carries nitrogenous and phoshate nutrients that increase the growth of aquatic plants and later undergo decomposition adding to organic loading of the streams. Excess algal growth has been of particular concern since algae lead to depletion of O_2 in water, create problems for municipalities and industries and make water unfit for recreational uses;

4. **Exotic organic chemicals**. Include surfactants, indetergents, pesticides, various industrial products, oils and decomposition products of other organic compounds. Good amount of oil along with waste products of industry reaches the sea and rivers. Oil discharges from coastal industries and from ships are most likely to be responsible for the tainting of fish and shell fish. Sea food with oily taints is highly objectionable and the suspected presence of tainted consignment can damage the market generally.

The most important groups of compounds which are both toxic and persistent are the chlorinated hydrocarbons including organochlorine pesticides, such as DDT, Dieldrin, BHC, Polychlorinated biphenyls (PCBS) and benzene products. All these accumulate in marine animals. Agricultural pesticides poison and kill millions of fish and other aquatic life. DDT may upset behaviour pattern in fish and survival of very young stages of molluscs and crustacea. PCBS compounds seem to be substantially less toxic lhan DDT but they certainly accumulate in marine animals in the similar manner. There is suggestion that they were responsible fot sea birds' deaths of the U.K. coast in 1969 but it could not be substantiated. Some plastic intermediate and the byproducts appear to be widespread in the sea.

Very insufficient information is available to assess their toxicity which may well accumulate in marine animals and plants.

5. Inorganic minerals and chemical compounds. Inorganic chemicals of many types find their way into waters through municipal and industrial wastes and the urban runoff. These pollutants can kill and injure fish and other aquatic life and they can interfere with the suitability of water for drinking and industrial purposes. Mercury, lead, cadmium and copper are the important metals that cause most concern. Other metals reaching the rivers and sea in substantial quantities are zinc and chromium.

Mercury occurs naturally in the sea as the result of weathering of mercury bearing rocks. It is also present in fossil fuels, coal and oils and reaches the sea by serial transport. It is highly persistent and said to be converted into a highly toxic methyl mercury (CH_3Hg) which produces nervous disorders in marine animals at an ordinarily low level of dietary intake. Normal level of Hg in fish probably ranges between 0·02 and 0·2 ppm. In situation exposed to industrial discharges containing Hg wastes in Japan, Sweden and North America, levels above 1·0 ppm have been found. Consumption of Hg contaminated fish may be hazardous to man. It is not known that anaerobic bacteria in bottom mud can convert Hg into methyl (CH_3Hg).

Lead is the natural pollutant of water, air and biosphere. Lead is accumulating in the marine environment as a result of drainage from rocks bearing the metal, industrial and domestic sources particularly the use of anti-knock motor fuels containing lead compounds. It has been calculated that motor vehicle exhausts contribute upto 2×10^5 tons of lead annually to the ocean through atmospheric transport. Much of this accumulates in the surface layer of sediments. One study based on geochemical relationships and material balances suggests that modern man absorbs daily 20 μgm lead from food, 1 μg from water and upto 10μg from urban air. Natural conditions are estimated to have ·01 ppm lead in food, ·0005 ppm in water and 5×10^{-4} μgm/m^3 in air. Although no ill effects have been demonstrated yet the rapid increase in the lead level in air and aquatic environment in recent years must be viewed with concern.

Copper and zinc have long been known to accumulate to very high level in molluscs where they may colour the flesh and render them unmarketable but marine fish do not exhibit this characteristic to the same degree. No toxic effects on consumers have yet been recorded.

Cadmium is also accumulated by some marine animals and is only slowly excreted. It is highly toxic but there is lack of information as to its biological effects.

Information regarding chromium is also very sparse.

Air Pollution

More subtle than water pollution is air pollution. The world Health Organisation defines air pollution as "limited to situations in which the out-door *ambient* atmosphere contains materials in concentration which are harmful to man and his environment." Air forms nearly 80% of man's daily intake by weight. A normal man breathes nearly 22,000 times a day inhaling about 16 kg air. Air pollution is not a new problem. Primitive man too introduced foreign substances into the air by way of burning and at her activities. The difference is that modern man accelerated the process of pollution and it has reached alarming proportins. Many of the long known effects of air pollution are reduction in sunshine, morbidity, mortality from respiratory ailments, dust fall, corrosion of metals and so on. Extensive experimental and epidemiological studies carried out in the 20th century and especially in the last few decades have verified these scientifically. The composition of unpolluted air is as follows :—

Constituent	*Volume*
N_2	78·09%
O_2	20·94%
Argon	·93%
CO_2	·032%
Neon	18 ppm
Helium	5·2 ,,
Methane	1·3 ,,
Krypton	1 ,,
H_2	·5 ,,
N_2O	·25 ,,
Co	·1 ,,
O_3	·02 ,,
SO_2	·001 ,,
NO_2	·001 ,,

Although the adverse effects of air pollution are well known, our existence in a pollution free urban atmosphere is still far beyond our reach at the present time. India's main problem of atmospheric pollution is due to the fact that 80% of industries in this country are concentrated in 10 or 12 big cities forming isolated pockets. Industrial chimneys, power houses, burning of fuels, autoexhausts etc. emit such pollutants into the atmosphere as suspended matters like smoke, dust and sprays, SO_2, CO, nitrogen oxides, fluorides, and silicon, tetrafluoride and foul odours. In Chembur-Trombay area in Bombay, where industries are concentrated, pollution rate is 3 to 6 times higher than that in other areas of the city. In Bombay some areas are found to contain high levels of sulphides which are probably caused by anaerobic marine environment and overloaded sewers. Calcutta is the most polluted city in India where carbon monoxide concentration is highest in the country (35 parts per million). The fertilizer factories of Gorakhpur, Ahmedabad, Sindri and many other cities are causing air pollution. Steel industries at Bhilai, Rourkela, Durgapur, Jamshedpur, oil refineries at Barauni and other places, the Neyvelli Lignite complex in Tamil Nadu and many other industries located in different places in India are causing heavy air pollution. G. D. Aggrawal of I.I.T Kanpur and D. K. Ghosh of H.B.T.I. Kanpur have tried to investigate the effects of most common air pollutants on respiratory diseases among a particular socioeconmic group of people in Kanpur which is one of the large industrial cities of India and is faced with such problem of air pollution.

Common air pollutants and their effects. There are two major factors which contribute to this problem of air pollution: increasing human population and increased productivity, each increasing by about 2 to 3% every year. The United States alone discharges roughly, 125 million tons of junk into the atmosphere each year and a conservative estimate for the whole world would be about 520 million tons every year·

The sources of atmospheric pollution are many and P. K. Zutshi of Bhabha Atomic Research Centre (BARC) in 1970 has classified sources of air pollution as follows :

Classification of Air Pollution Sources and Emissions

Type	*Category*	*Examples*	*Important Pollutants*
Combustion	Fuel burning	Domestic burning, thermal power-plants	Sulphur and nitrogen oxides
	Transportation	Cars, trucks, aeroplanes and Rail engines	Carbon monoxide, nitrogen oxides, lead, smoke, organic vapours, odours etc.
	Refuse burning	Open burning dumps	Fly ash and particulates.
Manufacturing processes	Chemical plants	Petroleum refineries, fertilizers, cement, paper mills, ceramics, clay products, and glass-manufacture.	Hydrogen Sulphide, SO_2, fluoride, odours, organic vapours and dusts.
	Metallurgical plants	Aluminium refineries, steel plants etc.	Metal fumes ($P\ G\ \&\ Z_n$) fluorides and particulates.
	Waste recovery	Scrap metals, gards, rendering plants.	Matal fumes, organic vapours, odours, smoke, soot etc.

Type	*Category*	*Examples*	*Important Pollutants*
Agriculture activities	Crop spraying	Weed and pest control	Organic phosphates, chlorinated hydrocarbons, Pb and Ag
	Field burning	Burning of refuse, firewood and dry dung	Smokes, fly ash, Soot. Sulphur dioxide, particulates and organic vapours.
Solvent-usage	Spray painting; Solvont extraction inks.	Furniture and appliances finishing, dyeing, printing and chemical separation	Hydrocarbon and other organic vapours.
	Solvent cleaning	Declearing, Degreasing etc.	
Nuclear Energy	Fuel fabrication	Gaseous diffusion	Fluorides
	Ore preparation	Crushing, grinding and screening	Uranium and Beryllium dust and other particulates argon-14, iodine-Bl.
	Nuclear device testing, Spent fuel processing	Bomb explosion Chemical Separation	Radiaactive fallout Sr-90, Cs-137, Cs-14 etc.

This main primary air pollutants oxides of carbon, sulphur and nitrogon, particulate matter and hydrocarbons. Besides these, there are some other pollutants of air. The important sources of air pollusants are motor vehicles (gasoline and diesel), aircrafts, rail and road transportation, coal, fuel oil, natural gas, wood fuel combustion, industrial processes, solid waste disposal, forest fire, agricultural burning, coal refuge burning, etc. Exhaust and other particulate matters in the presence of sunlight produce the photochemical SMOG which is no less than a plague. The December 1952 smog caused 15000 deaths in London within 5 days. Air pollution is clearly a great danger to man and it can lead to disastrous incidence. But not many are however aware of this fact that the air we breath is contaminated with dust and gases in harmful proportions.

Particulate matter : Solid and liquid aerosols suspended in the atmosphere are referred to as particulate matter. They arise from grinding, erosion, spraying etc. Aerosols are the chemicals which are released in the air with force in the form of a mist or vapour. Aerosols have caused serious environmental pollution in the recent years. Jet aeroplane emission is an important source of aerosols in upper atmosphere. Layers of pollution which are largely due to high flying commercial jets can be found as high as 43000 feet. Although smoke is popularly used to denote mixtures of particulate matter, fumes, gases and mists, 'dust' refers to solid dispersion aerosol and 'mist' to liquid aerosol. Dust particles greater than 10 μ in size are called settleable dusts. These are measured as dust fall in tons/sq. mile/month. Smaller particles suspended in air are referred to as suspended dusts. The aerosols contain fluorocarbon and fluorocarbons deplete the ozone layer in the stratosphere and thus permit more harmful ultraviolet radiations to reach the earth surface; ozone acts as a preventive covering against ultraviolet light. From the emission of supersonic aeroplanes nitrogen and sulphur oxides are released which also cause thinning of the ozone layer. Carbon tetra chloride (CCl_4) is also known to destroy some of the stratospheric ozone. Pilots have discovered pollution high over the middle of the oceans and north polar region.

The important effects of air pollutants are as follows :

1. Atmospheric particles can scatter and absorb sunlight, thus reduce the visibility. Reduced visibility is aesthetically undesirable and it is also dangerous for aircrafts and motors. In general, cities receive above 15 to 20% less solar radiation than rural areas and the reduction of sunlight can become as high as one-third in the summer and two-third in winter. The reduction in sunlight is largely due to fuel combustion for industrial and household heating purposes.

2. The effects of particulate matter include corrosion of metals, erosion and soiling of buildings, sculptures and painted surfaces and soiling of clothings and draperies, damage of electric equipments, etc.

3. The toxic effects of particulate matter on animals and human beings can be classified as :

(*i*) Intrinsic toxicity due to chemical or physical properties. Carbon monoxide in conjested areas removes 5 to 10% of blood from circulation. Although body tissues extract only 25% of oxygen from the blood, the heart needs 75% percent. So there is little margin for safety.

(*ii*) Interference with clearance mechanism in the respiratory tracts. Chronic bronchitis and emphysema have also been found to be caused by SO_2. A 24-hour exposure to about 0·2 ppm of SO_2 may cause serious health problems. Lung cancer has also been found to be correlated with air pollution. Polycyclic aromatic hydrocarbons (PAH) are found to be related to the pathogenesis of lung cancer.

(*iii*) Toxicity due to absorbed toxic substance.

Many toxic particles including metal dusts, asbestos, aromatic hydrocarbons have been discovered in a polluted urban atmosphere.

Lead from vehicle exhausts, resulting from the use of tetraethyl lead as an anti-knock additive to petrol, may build up to dangerous levels in urban areas adjacent to busy road complexes. Lead in high doses kills outright. In lower doses (in dense traffic) it shortens life span and causes deterioration of nervous system. Retarded children have a higher lead contents in their body than the normal ones.

4. Benzpyrenes—their concentrations are extremely small but they play a role in higher cancer rates in urban areas as compared to rural areas. Peroxyacetyl nitrates (PAN) or photochemical smog may constitute a serious problem where high levels of vehicular emissions occur in cities experiencing bright sunlight and ambient temperatures above 21°C.

5. The small solid particles can serve as carriers for micro-organisms and other infective agents and thereby may spread diseases. Large dust particles are trapped in nose and throat and very tiny particles which stay in the lungs may start an ugly chain of events leading to serious illness and death. Air pollution causes coughing, squeezing,thickening and secretion of mucus and narowing or complete closure of glottis due to presence of gases, especially SO_2, Nitrogen dioxide and oxidants. The silicon particles may cause 'silicosis' and fibrous particles 'fibrosis'. It is suspected that some pollutants can start the growth of lung cancer.

Sulphur Dioxide (SO_2). The most important air pollutant is SO_2 which is colourless, nonflammable gas with pungent irritating odour. About one-third of SO_2 present in the atmosphere is believed to be produced by man's activity. Robinson and Robbins (1971) have estimated that SO_2 from man's activity introduces 6·6 million tons of sulphur into the atmosphere annually. SO_2 present in atmosphere comes largely from coal and petroleum combustion. Biologically produced H_2S when oxidised produces SO_2. The following table gives an idea about the rough estimates of SO_2 and suspended particulates in air in major cities of India :

City	*Mean value of SO_2 (microgram/cum.)*	*Suspended particulate matter (microgram/cum.)*
Ahmedabad	10·66	306·6
Bombay	47·11	240.8
Calcutta	32·88	340.7
Delhi	41·43	601·1
Hyderabad	5·06	146·2
Jaipur	4·15	446·1
Kanpur	15·97	543·5
Madras	98·38	100·0
Nagpur	7·71	261·6

Source : NEE RI, 1970

Effects 1. SO_2 can damage materials and properties mainly through their conversion into the highly reactive H_2SO_4. It causes discolouration and physical deterioration of building materials and sculptures. Deterioration and fading are also produced in fabrics as cotton, nylon, rayon, leather and paper.

2. It accelerates corrosion of metals, especially iron, steel and zinc.

3. SO_2 has been found to affect vegetation adversely even at the concentration below ·032 ppm. It is suspected that sulphur dioxide pollution in urban and industrial areas of industrialised countries has a major impact on the respiratory condition of the population and also has significant effects on the crops and other vegetations of the surrounding rural areas. High concentration of SO_2 over short period of time can produce leaf injury, such as necrosis in plants or brownish colouration in the tips of pine needles. Lower concentrations over long period lead to chronic leaf injury such as gradual chlorosis.

4. SO_2 and H_2SO_4 both are capable of causing irritation in respiratory tracts of animals and humans and high concentrations of SO_2 cause severe heart and lung diseases.

Carbon monoxide. Carbon monoxide is colourless, tasteless, odourless gas which is deadly poisonous in higher concentration. It is one of the important gaseous air pollutants. It originates from incomplete combustion of carbonaceous materials. Man's activities raesult in the production of nearly 250 million metric tons of CO annually. Aircrafts are responsible for about 2·5% CO and 1·1% hydrocarbons in USA. Space rocket engines produce many dangerous exhaust products. In one study it was found that engine of Appollo Lunar module which took two astronaunts to the surface of moon produced NH_3, water, CO, NO, O_2, CO_2 and N_2O as major exhaust products and wide variety of different minor exhaust products. The toxic effects of CO on human beings or animals arise from its reversible combination with haemoglobin in the blood. Haemoglobin has much greatar affinity with CO and it lessens the oxygen carrying capacity of blood. It also reduces the dissociation of oxyhaemoglobin.

Nitrogen oxides. Robinson and Robbins (1971) have estimated that biological production of NO and NO_2 amounts to about 1 billion metric tons anuually while man's combustion processes produce 48 million metric tons NO_2 annually. Man made nitrogen oxides pollution is insignificant in urban areas. These oxides play important role in production of photochemical smog.

The effects of nitorogen oxides are as follows :

1. Nitrogen oxides are known to produce fading of textile dyes, deterioration of cotton and nylon and corrosion of metals due to production of particulate nitrates.

2. NO_2 causes leaf injury and reduction of growth in several NO_2 sensitive plants.

3. It affects lung, heart, liver and kidney at higher concentrations (15 to 50 ppm for two hours). Besides, it is considered to be a major factor in causing eye irritation.

Hydrocarbons. Many hydrocarbons are known to be present in the atmosphere as pollutants. Natural sources of hydrocarbons are largely biological. Worldwide methane production mainly from anaerobic decay of organic matter probably amounts to 1 billion metric tons annually. Some plants produce volatile tarpenes. In urban areas, ethylene is known to inhibt the plant growth. Open chain hydrocarbons affect human beings. Aromatic compounds cause irritation and injury in the mucous membrane at 500 ppm. Hydrocarbons are of particular concern because of their involvement in the production of photochemical oxidants which cause irritation and other effects.

Air pollution due to odours. Many chemical compounds, perfumes, whiskeys and wines and many other rotten substances emit undesirable smells which pollute the local atmosphere. Sometimes only through odour quality of food or identification of particular chemical is measured and many edible things are evaluated only through odours. In dairy industry also smelling and testing of milk and its products may be used to determine the quality of raw material. Such testing is made only by experts. For food and perfumery industries, correct odour is essential.

Odour is a smell which can be determined by the nose. According to Karolinska Institute symposium on Enviromental health "a product of the activation of the sense of smell, an olfactory experience is called odour and any chemical compound which can stimulate the olfactory sense is called odour. Odours are described on the basis of both intensity and characters.

Odour is a physiological response of individual person. There are some instruments which can measure the physical or chemical characteristics of odour indirectly but these instruments are not better than human nose to determine the smell.

Other Air pollutants. A number of other minor emissions such as vapour resulted from cosmetics, the smoke from tobacco products, aeroallergens (spores and pollengrains) which cause allergy in some persons are also regarded as air pollutants. Industrial processes especially chemical industries produce special air pollutants such as H_2SO_4. HCl, formaldehyde, alcohols and many other chemicals. A particular air pollutant that has attracted special interest in the recent years is asbestos. Its occupational hazards are well known since 1943. All the urban dwellers are exposed to asbestos pollution. Pesticides and radiations are other important pollutants which are very dangerous for human health.

Agricultural Pollution

Improved agronomic practices, artificial fertilizers, farm chemicals and improved methods of preserving and transporting food are playing roles in agricultural pollution. Although air and water pollutions have affected agriculture adversely, agricutural methods themselves have contributed to environmental polllution. Some of the important agricultural pollutants are as follows :

Farm animal wastes. Over the century farm animal wastes, such as faecal matter, wine, wastes from slaughter houses, dead animal wastes, have been regarded as important sources of soil fertility. In addition, the presence of farm animal wastes poses serious problems of foul odour and water pollution. Sometimes public health problems arise from their role in transmitting diseases. Animal wastes pose serious problems when they enter the water supplies.

Soil erosion Eroded materials add fertility to the soil. Strong winds carry soil particles into the air and water and thus produce air and water pollution. When they are carried to the streams by storms or by run off water they settle at the bottom and destroy irrigation systems. Sediments can clog gills of fishes. It interferes with the industrial uses of water and leads to extra-expenses for clarification' of water. It can reduce the dissolved O_2 level and thereby it adversely affects aquatic life. It affects the recreational values of lakes, reservoirs and streams. Control of soil erosion consequently can control the environmental pollution.

Plant residues. Plant residues from crops, fields, orchards contribute much to environmental pollution. They carry plant diseases and pests. When they are burnt they emit smoke and hydrocarbons. Since both the situations correspond to an unfavourable alteration of environment, agricultural burning is important pollution problem. Burning of plant residues gives—

8·3% CO,
8·5% particulate matter,
5·3% hydrocarbons,
1·5% Nitrogen oxide.

Much of these burnings are for sanitation purposes since plant debris can carry diseases or pests for succeeding crops. Agricultural burnings and the resulting air pollution are likely to continue until better methods of controlling the plant diseases are available.

Agricultural Chemicals. In recent years there has been an increased use of agricultural chemicals, notably pesticides, fungicides, rodenticides, herbicides and fertilizers. Thus agricultural chemicals have no doubt increased crop yields but they contribute air and water pollution to a significant level. They have many adverse effects on fish, wild life and sometimes human beings. Excessive application of fertilizers may create problems since fertilizers can be transported to ground water by leaching or to water ways by natural drainage and surface runoff. Nitrates in drinking water can cause methamoglobinemia in babies (blue bodies), because in infant's stomach the NO_3 is converted into NO_2 which when reaches in the blood reacts with haemoglobin to form methemoglobin. Phosphorous is often implicated in algal blooms in waterways.

A. Insecticides. Farmers and gardeners use pesticides to avoid the damage of crops and pests. Insecticides have come in use from the last decade. Mitter discovered DDT (Dichlorodiphenyl trichloroethane) which is the first chlorinated hydrocarbon to be used as pesticide. Later on other pesticides were discovered. Insecticides are classified as :

(*i*) Stomach poisons, (*ii*) Contact poison, and (*iii*) fumigants.

(*i*) Important *stomach poisons* are arsenic and fluorine compounds, lead arsenate inorganic fluorine compounds, such as cryollite, sodium fluoride, mercury compounds (HgCl, $HgCl_2$), boron compounds (borax and boric acid), chlorinated hydrocarbons, arganophosphates, carbamates, and certain botanical compounds as pyrethrum (Powdered flowers of chrysanthemum), nicotine. Arganophosphorous compounds are most toxic insecticides that affect insects and mammals. Many of them (parathion, thimet, phosdrin, paraxon) are supertoxic and are human poisons giving many symptoms as nausea, vomiting, diarrhoea, sweating, salivation and muscular tremors.

(*ii*) *Contact poison insecticides* are chlorinated hydrocarbons and its metabolites, *e.g.*, DDD, TDE, BHC, DDT has primary effects on central nervous system. In the environment DDT is degraded into different forms. Chlorinated hydrocarbons are known to be present in the body of fat human beings, the main source being food supply. Studies have shown that daily content of DDT in meal is about ·04 to .5 mg or more.

Hydrocarbons persist in the environment for long time and affect large number of insect species but are responsible for undesirable side effects.

(*iii*) *Fumigants.* There are gases which are used to kill pests of stored products or nursery stock, *e.g.*, methyl bromide, carbon disulphide, carbon tetrachloride, nicotine, naphthelene, phosphine and other copounds.

B. Fungicides. These are used to prevent fungal pathogens of plants. Sulphur, organic mercuric compounds, formaldehyde, copper sulphate and some others are commonly used.

C. Herbicides. These are chemicals which kill herbs. They are of two types :—

(*i*) *Non-selective herbicides* which kill all the plants, examples Sodium arsenite, Sodium chlorate, H_2SO_4.

(*ii*) *Selective herbicides* which kill only certain types of plants. Most commonly used herbicides are 2, 4—D and 2, 4, 5—T and their esters and growth regulating substances.

D. Rodenticides. They are used to kill rodents, rats and mice. Some have direct immediate action, *e.g.*, Strychnine, Sodium fluoroacetate, P-thallium and ANTV. Others are anti-cloagulants.

Radiation Pollution

P: K. Zuthshi of Health Division, Bhabha Atomic Research Centre (BARC) has thrown sufficient light on the problems related to radioactive pollution in a paper entitled "Environmental pollution studies at B.A.R.C." published in "Nuclear India" Vol.9, No. 12, Aug.,

1971. All atomic energy installations in the world are provided with an almost fail-safe device and an international standard for radiobiological protection is strictly followed for safe guarding animal and human health. Despite rigid controls, however, there is an unavoilable release of radioactive effluents into the environment. This effluent is monitored and regulated continuously by health physicists in the establishments concerned. In India this work is largely done by health physics division of the Bhabha Atomic Research Centre, Trombay. Protection against radiation exposure from use of radioactive materials in industries and research institutions all over the country is looked after by a separate all-India organisation—the Directorate of Radiation (D.R.P.). The D.R.P. keeps track of radioactive materials with users, instruct them in their use and keeps a watch on exposure of the users or the public at large to radiation.

Fallout of nuclear explosions. Low level radioactive liquid wastes, radioactive gases and dusts are released from nuclear installations. The liquid wastes are released into the waters and the gases are disposed through high stacks. Besides stack emission from nuclear installations, there is worldwide fallout of radioactivity from atomic bomb tests. BARC has been assessing exposure of the population in India to radioactivity arising from nuclear tests explosions. It is also studying the atmospheric air circulation pattern by which radioactive pollutants are dispersed on a global scale. Level of radioactivity after test explosions is reported to be insignificant for short period immediately after explosions but it increases appreciably after sometime and subsides within a few weeks. Radioactive fallouts have been observed from the upper atmosphere where the debris of tests explosions stays for a long time.

Hoda, M.M. 1977 in his article on "*Nuclear Energy and Environments*" high lighted some of the problems relating to hazards of radioactive materials. Much has been said about the nuclear weapons, although at least there is great possibility that it may not be used again the greatest danger to humanity is now posed by the so called peaceful use of atomic energy but not so many of us realise this fact. While man can and does create radioactive elements there is nothing he can do to reduce their activity once he has created them. No physical interference, no chemical reaction but only the passage of time can reduce the intensity of reduction once it has been set going. The fission of Uranium 235 results in a mixture of a number of long-lived and short-lived isotopes. The disposal of radioactive wastes presents enormous problem. It was thought at one time that radioactive wastes could be safely dumped into the deepest part of the ocean on assumption that no life could subsist at such depth, but within a short time after dumping these materials in water the great bulk could be found in the living organisms. No international agreement has been reached so far on disposal of nuclear wastes. Nuclear wastes with high level of radioactivity continue to be dumped in to the sea while large quantities of so called "*Intermediate*" and "*Low level*" wastes are discharged in the rivers or directly into the ground. An Atomic Energy Commission report observes that liquid wastes "work their way slowly into ground water, leaving all or part of their radioactivity held either chemically or physically in the soil (U.S.A.E.C, Annual Report to Congress, Washington D.C. 1966, p. 344). The nuclear reactor, after they have become unserviceable, are most massive wastes. The reactors have an average life of 30 years and they cannot be dismantled and shifted but have to be left standing where for centuries silently leaking radioactivity into air, water and soil.

There is no fail proof method of disposal of radioactive wastes. In many cases the radioactive wastes are sealed in steel drums or concrete blocks and sunk into sea to await their natural decay. The pollution of aquatic environment by radioactive materials forms a special and very complex type of problem. Radioactivity may pose serious problems as radioactive isotopes can produce not only immediate effects on living organisms but even more important, can produce mutations in the genetic materials which would have serious consequences for the later generations. Radioactivity can reach the aquatic environment from a variety of sources such as nuclear fallout, nuclear powered ships and submarines, nuclear power plants, laboratory experiments with medical uses of radioisotopes and so on. Desalination and Effluent Engineering Division at BARC has developed high efficiency particulate filters for air pollution control from hazardous contaminants, such as radioactive isotopes from nuclear operations installation and compounds of such toxic elements as Berylium and Tellurium.

The effects of radioactive elements is difficult to judge unless they are in such concentrations as to give acute effects, malformation of body at birth, abnormality in organ development are some of the effects observed in the laboratory animals.

Thermal Pollution

Heat or thermal pollution is common to both nuclear and conventional sources of energy production. It can be both an air and water pollutant. Waste heat is not only the cause of widespread climatological changes but also it can cause damage to aquatic and terrestrial life. The thermal discharges are usually favourable to bacteria and pathogens. Rapid temperature changes produce thermal shocks and result in immediate death of fishes. Temperature of the environment controls reproductive cycle, digestion rates, respiration rates and many chemical activity taking place in the body. As the temperature of water increases its viscosity decreases, the vapour pressure increases, and solubility of gases in water decreases. These changes have important effects on aquatic life.

Noise Pollution

In addition to the disturbances caused by air pollution, a new kind of disturbance has come into prominence. This is called-"noise pollution". Noise is unwanted sound. It has been regarded as urban pollution. It has become serious in urban areas due to over population, different kinds of sounds produced by machines etc. Some of effects of noise pollution are given below :

(1) Prolonged exposure to noise are known to lead to gradual deterioration of internal ear and to subsequent hearing loss or deafness. Hearing loss problems are especially severe in certain industries. Medical authorities are generally of the opinion that constant occupational exposure at higher frequency is dangerous for human beings.

(2) Noise also clearly produces annoyance in human beings and can interfere with proper rest and sleep. Annoyance seems to increase with the loudness of the sound.

(3) Noise also produces psychological effects in human being.

(4) One important effect is the vasoconstriction reflex in which small blood vessels of the body constrict and reduce the flow of blood.

(5) Physiological effects of noise include dilation of the pupils, paling of skin, tensing of voluntary muscles, diminishing of gastric secretions, increase in diastolic blood pressure and the sudden injection of adrenalins into blood stream which increases neuromuscular tension, nervousness, irritability and anxieties. It can adversely affect the development of unborn babies.

Impulsive noises and thunders are worse than continuous noise which, if loud enough, cause sudden damage to hearing loss. Sudden noises also startle persons and lead to accidents. Supersonic booms produced by objects travelling faster than the speed of sound produce shock waves which deviates from atmospheric pressures.

Control of Environmental Pollution (Environmental management)

The recent growing concern for the quality of our environment has strengthened the concept of environmental monitoring which requires regular periodical measurements of environment followed by timely assessment and interpretation of data obtained. Reliable monitoring data are necessary to know pollution problem.

Environment is deteriorating day by day due to industrial pollution, toxic chemicals, automobile emission and natural resource depletion. Pollution in its various forms is increasing tremendously. Environment management is to study all these things and check over pollution. In other words, environment is satisfying basic human needs at the minimum and more if possible, for an indefinite future. The main aim of environmental management is overall development of environment. By environmental management it is to see whether air is fit to breathe, water to drink and soil and sea resource is fit to provide all needs. One also expects that people are well fed, well housed, well schooled and enjoying happier and healthy life.

Environmental problems are so diverse and diffused that virtually any activity of civilization interacts with the environment. Many environmental pollution problems are local in character and they can be controlled by creating environmental consciousness in each and every citizen. People should be told about the importance of clean atmosphere as well as about the consequences of different types of environmental pollutions. Besides, action is also needed at national level although guidelines may be established internationally as the result of pooling of scientific knowledge, as for example, through the United Nations Joint of Experts (GESAMP). Some of the effective and practical control measures for minimising environmental pollution are outlined below :

1. Combustible solid wastes should be burnt in incinerators. This method does not solve the problem in a real sense because in this, solid waste is being converted into gaseous wastes causing air pollution. Unless it is properly controlled, incineration may cause more nuisance.

2. Solid organic wastes including faecal matter and wastes from tanneries should be converted into compost manure at the places far away from the cities and dwellings. The composting should be done in pits or in heaps adequately covered with layers of soil at least 8—10 cm thick to prevent fly breeding and rat menace which are important carriers of various diseases.

3. Non-combustible solid waste materials like ash, rubbish, tins, glass pieces if not recoverable for usual purposes should be disposed of by landfill method in low-lying areas.

4. Anaerobic septic tank treatment can be used for individual houses or small communities. Besides, aerobic biological treatment systems including trickling filters, activated sludge treatment and oxidation ponds can also be used for liquid waste or sewage disposal.

5. Automobiles must be either made to eliminate the use of gasoline and diesel oil or complete combustion is obtained in the engine so that noxious compounds are not emitted. The automobiles, trucks and other transport systems must have an antismog device. In some countries factories are using devices like scrubbers, cyclone separators or electrostatic precipitators to minimise pollution.

6. There should be cutout or cut back in the use of fertilizers, herbicides and pesticides as far as possible.

7. Excessive and undesirable burning of vegetation should be stopped.

8. Sponge and towels should be used in place of paper towels and also the use of paper cups and plates and similar materials should be stopped.

9. Little use of fewer electric appliances and fewer motor-run appliances will reduce thermal pollution.

10. Washing soda and scouring pad should be used instead of detergents.

11. Used boxes, bags and bottles should be reused whenever possible.

12. Since about 40% of the phosphates in water pollution come from detergent, it has been suggested that only detergents low in phosphates should be used.

13. Shampoos, lotions and similar products should not be bought in plastic bottles. It has recently been suggested that use of plastic containers and glasses may cause cancer.

14. Smoking should be stopped (there are 5,00,000, tons of tobacco pollution annually).

15. Proper attention should be given by the government and general public to realize the implications of environmental problem.

16. Legislation should be passed against pollution.

17. International action is needed to deal with the problems presented by highly toxic pollutants like lead, mercury, organochlorine pesticides released to the atmosphere and carried far beyond their country of origin as well as carried down to the sea by rivers. Successful action to improve environmental qualities depends mainly on the acceptance by industry and local authorities of the need to reduce greatly both quantities and toxicity of certain wastes at present being discharged into the sea and the modernization and expansion of sewage disposal systems.

18. Environmental education is the best programme to deal with the environmental problems. It is most fundamental in our efforts to combat and control pollution, over-population and misuse of natural resources. Environmental education include the following objectives which are based on the major outcome of the 1975 workshop on environmental education.

(*i*) Creation of Awareness of the problems.

(*ii*) Providing knowledge to deal with the problems.

(*iii*) Developing new attitudes towards environmental problems.

(*iv*) Developing skills for solving environmental problems.

(*v*) Providing development of evaluation ability in these areas.

(*vi*) Increasing participation and involvement.

(*vii*) A broad recognition of the facts that we are all responsible for helping to solve environmental problems.

Recycling of waste

The work on pollution control and abatement techniques is being done by Desalination and Effluent Engineering Division of **Bhabha Atomic Research Centre (BARC).** There is a special Directorate of Radiation Protection (DRP), an all-India organization, which keeps watch on exposure of the users or public at large to irradiation and provides proper instructions to users for using radioactive materials. Besides these, a National Environmental Engineering Institute (NEEI) at all-India level is established at Nagpur to execute studies on different aspects of pollution. This institute has 8 regional offices, one each in Tamil Nadu, Calcutta, Bombay, Delhi, Hyderabad, Jaipur, Kanpur and Ahmedabad. One more all-India organization, Toxicological Research Institute, has been established at Lucknow which is concerned mainly with the study of toxicological problems.

Action Committee of 68th session of Indian Science Congress held at Varanasi (1981) recommended the following points on environmental management :

1. Immediate implementation of acts against air pollution, water pollution and noise pollution.

2. There should be specific standard for the use of agricultural chemicals, such as insecticides, pesticides and fertilizers.

3. Action is necessary against food adulteration, drug control and factories producing effluents.

4. Department of Environment should be empowered for initiating legislative measures by the Parliament. Department should have control of soil, air and water environment and should maintain a strict vigilance over metropolitan and industrial areas. There should be regular monitoring of air and water quality. Penalty on offenders not adhering to set standards against air, water, noise and other sources of pollution should be imposed.

5. Environmental protection should be included in the concurrent list of Constitution.

6. Government and voluntary agencies should be provided special incentives for successful anti-pollution researches.

7. Department of Environment should carry out publication of Health and Safety Directorate criteria for differant pollutants.

8. Environmental education should be made compulsory in the curricula of schools, colleges and universities.

9. Mass communication media should be adopted for information related to environmental problems.

10. Scientific societies, Associations and Academies should create a temper of environmental problems in the rural and urban areas.

11. Plantation of trees suited to different climates should be adopted. Deforestation must be legally checked.

12. Wild Life Board and Environment Cell should be created in each state.

13. Recycling plants for municipal waste and sewage should be established.

14. Anti-pollution tax should be imposed on industries for discharging the effluents.

15. Reclamation of land to its orginal state should be the responsibility of the users. There should be legislation against violation for this.

16. Encouragements and incentives should be given to voluntary movements as "Chipko movement" for the protection of plants.

17. In agriculture biological control of pests should be applied to replace wide use of insecticides, pesticides and fungicides. Biological nitrogen fixation should be adopted.

18. Several Biosphere reserves containing endange. rare o

commercially important species should be established as early as possible.

19. Gene Pool Reserves and Gene Sanctuaries should be demarcated and protected in their natural environment to preserve wild germ plasm from extinction and conservation.

20. For conservation of flora and fauna the list of endangered species should be continuously renewed.

21. Aero-biological centres should be established in different parts of India.

22. Brick fields should be prohibited by law near agricultural or populated areas.

23. Cleaning of choked lakes and rivers should be done regularly.

24. Different aspects of energy sources should be created as biomass, energy plantation, fuel energy etc. Social forestry should be encouraged.

25. A suitable agency should be established for conservation and monitoring of marine resources and providing protection against pollution hazards.

26. Satellite and space technology may be adopted for weather forecasting, agriculture resource inventories and monitoring of air-borne particles.

27. Air port areas should be separated to minimise pollution from noise.

28. Genetic counselling units should be established at different regions of India to monitor genetic disorders.

29. Scientific, administrative and social measures must be adopted to check pollution explosion.

30. At different levels of planning, the involvement of ecologist is essential. All programmes for development should be undertaken without or with the least disturbance to the natural ecosystem.

QUESTIONS

1. What is pollution ? What are the various pollutants causing pollution ? What are their effects ?
2. What is air pollution ? In what ways man is affected with air pollution ?
3. What is water pollution ? Describe various kinds of water pollutions and their ecological effects on the aquatic organisms and man.
4. What is environmental management ? What are the various control measures for minimising environmental pollution ?
5. Write short notes on

   Thermal pollution, Noise pollution, Radiation pollution, Hydrocarbons, Pesticides and their effects, Aerosols, Agricultural pollution.

14

CONSERVATION OF NATURAL RESOURCES

Man lives in nature and depends on the resources of nature. The progress of mankind depends upon the exploitation of different natural resources. The utilization of soil, water, coal, electricity, oil, gas and nuclear energy is very important for the development of nation. These resources have changed the level of living standard of man.

Of the world total population of four billion, one million in U.S.A. and Europe alone use 84% of world's total energy. Two billion people of India, China, Brazil and few other countries use only 15%. India contains the world's largest resource of coal and third and fourth largest resource of manganese and iron. Fossil fuel (coal, petrol, and natural gas) on which modern industrial centres are based, are limited. At present rate of consumption, fossil fuel may be drastically depleted leading to severe energy crisis. Oil reserves of the world are higher than petroleum and natural gas and they may last longer. The leading coal producing countries are China, U.S.A., U.S.S.R., Germany, U.K. Japan, India, Poland, France and Czechoslovakia. The major oil producing countries are U.S.A., U.S.S.R., Kuwait, Saudi Arabia, Iran, Iraq, Nigeria, Libya, Arab Republic and Indonesia. New discovery of oil has been explored recently in the sea beds of Bombay.

India is facing an ecological crisis and is degrading her natural resources day by day. Now the shortage of natural resources is a matter of international concern. There is increasing deficiency of energy, metals, coal, non-fuel and non-metallic minerals. With regards to fuels there is great concern over the huge outflow of foreign exchange and every year enough oil is purchased from the Middle East countries which are major resources of petroleum. The developed nations of the world have created abundant resources but the developing nations are importing many of these from foreign countries.

We all are aware of the fact that earlier the human being was essential part of the nature and human society has impact on the other components of the biosphere. However, with the advancement of social and cultural evolution which came in the twentieth century there has been a growing conflict between man and nature. Due to unending human greed man has destroyed the nature to the maximum for his little gain and made him to assume as the master of nature. However, all human efforts to have mastery over the nature, have only resulted his further dependence on nature. On account of such unthoughtful and ruthless exploitation, the human society has vastly modified the ecosystem found in different parts of the world and has brought undesirable changes in the natural habitat. Consequently, the natural stock of plants and animals has disappeared. About 1000 species are currently threatened with extinction or are dangerously rare. The human encroachment with nature, has deprived the world civilization of 130 mammal species and has endangered more than 250 species. Out of the total of approximately 0·3 million species of plants in the world, over 20,000 are in the category of either endangered or threatened with extinction by the year 2001 A.D.

Food, shelter and clothing are the primary requirements of man. Early human society has used natural resources, relatively in much less quantity to cover his wants. Among them, most essential requirement is a well cooked food. We know that cooking requires energy. The simplest form of energy available for cooking since the early human history is fuel wood. According to an estimate about 60·5 per cent of Indian people's consumption is fire wood and other agricultural wastes. According to Government of India's "Fuel Wood Policy Committee", the annual demand for fuel is roughly 133 million tonnes which is expected to increase to about 270 million tonnes by 2001 A.D.

There is a great controversy over the sufficiency of the mineral resource to retain domestic, economic development all over the world. According to "Resources and Man" (1969), "True shortages exist or threaten for many substances that are considered essential for current industrial society." Mercury, tin, tungsten and helium for example known and now prospective resources of these substances will be nearly exhausted by the end of this century or early in the next, and new sources or substitutes to satisfy even these relatively term needs will have to be found.

One of the most serious aspects of the problem arises from the impact of economic efforts of mankind especially for the purpose of maintaining its existence, protection, survival and betterment of the standard of living. The basic needs which induced the human beings to spoil the natural resources for their welfare have finally led to a situation which threatens to be disastrous. Now in almost every advanced country, the overpopulation has been vitally concerned with the atmospheric pollution. Every effort is being made to save mankind from self-destruction. The situation has become so serious that it is necessary to take some precautionary steps so that the complications may not become worse further. Now there are various problems which have arisen due to industrial and agricultural developmental activities from pollution. Many of these problems are due to mismanagement of natural resources and the impacts are not localized but are universal in nature. It has been estimated that the quantity of CO_2 will be double in 23 years and all the oil and natural gas resources will be no more available after 50 years and coal will be almost consumed within 150 years.

There are four basic reasons of the depletion of natural resources :

1. Rapid population increase
2. Pollution
3. High consumption of resources and
4. Deterioration of land.

1. **Rapid Population increase**. There is a tremendous increase in India's population and it will be about 10 billion by the end of this century. An increase in population will decrease all types of natural resources and consequently result in environmental pollution. Ultimately there will be short supply or deteriorating quality of natural resources. This is because increase in population will increase the demand of natural resources and environment.

At present the world population is 3600 million and is increasing by two per cent per year. The industrialized countries have annual growth rate of 0·5 to 1 per cent and on the other hand the developing countries have the growth rate of 2 to 3 per cent. The per capita use of energy and mineral resources shows a difference between the developing and developed countries of the world. The developed countries consume less but their resources are enough. The population and per capita consumption has a considerable impact on the environment. The world can not meet the continued increase in natural resources demand.

2. **Pollution**. We are deteriorating our environment due to increasing population. We are polluting lakes, streams, rivers by sewage, industrial wastes, heat, radioactive materials, detergents, fertilizers and pesticides. Besides these, we are releasing number of toxic materials into our surroundings. Our controlled and indiscriminate use of pesticides has disturbed the entire food chain by which animals including man are affected. Similarly, it has been estimated that average individual has about 7 parts per million (PPM) DDT in his body which affects in long term. Recent researches have revealed that this proportion of DDT in our body has deleterious effects on heart and liver and higher concentration may cause several other diseases including cancer. Many cases of carbon monoxide, sulphur dioxide, carbon dioxide and nitrous oxide are known to cause the respiratory troubles. The unplanned and uncontrolled industrial growth may affect adversely and will destroy the health of the society.

3. **Consumption of Materials**. Due to tremendous increase in population most of the natural resources are being con-

sumed. This high rate of consumption has disturbed our ecosystems. But on the other hand, many of the natural resources are essential to man for basic needs. Many industries require raw materials which are essential for the advancement of the country. However, there is no doubt that high consumption will affect adversely the quality of our environment either by using natural resources unwisely or by increasing pollution.

4. **Deterioration of Land**. Due to excessive consumption of minerals of the soil by cropping or soil erosion or other natural events fertile soil is lost and land deteriorates gradually. Sometimes drought has also resulted into a deteriorating land and many nutrients of the top soil are destroyed and their fertility is lost. As a result of cropping, the mineral cycling of soil nutrients is greatly reduced.

Erosion has also depleted soil fertility because most of the minerals remain in the upper part of the soil and they are easily removed by wind or washed away by water. Sometimes water erosion has taken its toll of fertile soils.

Man has also deteriorated agricultural land and ultimately in the loss of national economy. It is commonly seen that man can not degrade one part of his environment without simultaneously affecting other parts.

Now proper requirements of land for cropping, forest recreation, urban land, transportation and wild life are needed but they are reduced day by day. Therefore, integrated policy of intelligent resource management should be practised, otherwise unexpected future shortage might upset the national economy.

Different types of natural resources and their conservation

Basically the natural resources may be of two types :

1. **Renewable natural resources**. These resources can be replenished again and do not change the ecological balance. The cut trees can be grown again, soil forms again and animals reproduce themselves.

2. **Non-renewable natural resources**. Resources which once used up, will be exhausted for ever.

It is clear if the man wants to continue to survive on this planet he must conserve the natural resources rather than merely exploit them. It does not mean merely preservation of the resources without using them. We should use the resources wisely and judiciously without wasting them.

Different types of these natural resources and their conservation is given under the following headings :

Mineral resources. Now it is known that the world resources of minerals, oils, coal and natural gas are limited. Mineral resources are of several types : Metallic minerals and non-metallic minerals or industrial minerals include a wide variety of substances which comprise the building materials such as rock, sand, gravel, cement and clay. The non-metallic minerals are fertilizers which supply N.P.K., are essential to increase agricultural yield. Large amount of nitrogen in the form of nitrates is available in the form of natural deposits but now it is possible to fix nitrogen synthetically from air. Thus, the deficiency of nitrogen resources is compensated. Phosphorus is obtained from phosphate rocks. Although the world resources are abundant, but it is not evenly distributed. Potassium is also quite abundant in the world.

Among metals, iron, nonferrous metals, silver and gold are important. Among these iron is the most important element because it is the main component of steel. Chromium, Cobalt, Magnesium, Molybdenum, Nickel, Tungsten and Vanadium are included under ferro-alloy elements.

So far as the causes of mineral loss are concerned, soil erosion and cropping are considered to be most significant. Most of the soil nutrients remain on the upper part of soil and many fertile minerals of upper soil are carried away by rapid winds or running water and soil becomes deficient of fertile minerals as we know that the soil is the most important irreparable resource of nature. It is essential for human existence which provides the basic requirements to man.

At present there is a greater loss of minerals all over the world which should be considered seriously. Future demands for mineral resources must be thought of seriously. Although it is difficult to make exact estimate but there should be proper relation between demand and supply. Sudden shortage of mineral resources results in poor economy. Now it has been estimated that for the number of important minerals the resources are so limited that new resources must be supplied immediately otherwise the minerals will be exhausted in a few years. Due to excessive consumption new minerals should be added rapidly. Now it has become essential to resource-producing undeveloped countries to make some Act to maintain control over their own natural resources. Eleven oil-rich countries have an International Organisation of Petrol Exporting Countries (OPEC) which produces more than 50% oil of the world. It has been calculated that out of 19 important minerals 9 would be exhausted in 10 years and Coal, Iron and Aluminium will be consumed by 2000. Therefore, entire quantity of world reserves should be replaced time to time.

There are three important approaches which should be taken into consideration :

(*i*) To reduce wastes and to minimise demand

(*ii*) By changing the way of life

(*iii*) To increase reclamation and recycling of materials.

Solid wastes should be reutilized for their energy content and it is possible to recycle the materials and reserve is to be met by reclamation. Increasing the amount of reclamation, the total demand can be met with a decrease in the consumption of new materials.

Forest Resources

Forest is an important natural resource. It is most important natural habitat for wild life. It is also utilized by farmers and commercial and recreational purpose. Many herbivores find shelter and carnivores search their prey in the forest. Many wildlife store food supplies and breed in the forest. Besides this, forest plays most important role from commercial point of view. It is the source of a large number of products useful to man. It provides raw materials for many products of daily use. It feeds several industries which depend on wood products. Terpentine oil, many paints, resin and printing paper get raw material from the forest. Not only this benefit from forest, it also gives recreation. Forest also provides sanctuary for the modern city. Large number of people visit the forest for peace, beauty and recreation. Forest based cotton industry such as bee-keeping, bamboo mat and basket making provides small-scale industry to the tribal people. Sal is a most important source for timber industry. It also provides raw materials for pulp and plywood industry.

Green plants of the forest are food-producing organisms and are primary producers of the "food chain". They trap energy from the sun and use it to transform CO_2 from the air, together with water and nutrients from the soil into food substances, like starches, sugars, through the process of photosynthesis. These foods are stored in the form of fruits, nuts, seeds, nectar and wood. Therefore forest serves as an energy reservoir, trapping energy from sunlight and storing it in the form of a biochemical product.

Forest plays a most important role in keeping the atmospheric balance by consuming CO_2 and releasing O_2, the latter essential for animal life. So removal of plants and trees would disturb the composition of natural air. An acre of forest absorbs 4 tonnes of carbonic acid gas and recycles 8 tonnes of oxygen into environment.

If a forest is cut down, energy stored in the wood is lost but also most of the nutrients of the system are lost. Such deforestation leaves a poor soil which can support agriculture for only a short time, because the harvesting of the first few crops removes the remaining nutrients and renders it to useless. Deforestation causes other disastrous results also. Removal of trees exposes the surface of the land resulting into erosion. Soil is then washed away. In many places soil erosion occurs ten times more rapidly than usual, once the trees are removed. Soil erosion is particularly more on hill sides, where heavy rain sweeps soil downhill to choke rivers. The reduction of forests affects later rainfall and thereby restricts the availability of a most important natural resource, rain water.

In natural forests, the tree roots bind the soil and about 90 per cent of the rain falling on the forests is retained either in humus or in the plant tissue. The forest thus acts as a soaking device and plays a vital role in the hydrological cycle. The rain water thus soaked up is gradually released over the days and weeks which supply to streams and rivers even during dry seasons. Hence, it is important to retain forest cover in upland catchment areas as an alternative to flooding the whole area barren and unculturable. This washed away top soil silts river beds, reservoirs to reduce their holding capacity and flood in the surrounding area is a natural calamity. It has been estimated that in India 60,000 million tonnes of top soil is carried away annually by rain water from deforestated area.

Nowadays the tendency of deforestation is increasing day by day. Man is cutting forest to get temporary benefit but there is a tremendous loss in due course of time. Now due to gradual destruction of forest wild life is disappearing and their number is becoming reduced for which government should consider various aspects of forest management. Forest management programme should be motivated by forest employees and general public to increase yield, to avoid forest cutting and pest and fire control. Whenever plants or timber is cut, that area must be reforested. Similarly any forest which has been destroyed by insects, disease, hurricanes should be reforested again. The primary aim of the forest service is to make the greatest number of forest resources available to the greatest number of people.

Shifting cultivation is another practice which destroys the forest. Many farmers destroy the forest for agricultural purpose and soil is exhausted. Therefore farmers should use the same land for cultivation and they should apply better farming methods so that soil fertility remains restored and can be used again.

Nowadays most severe damage of the forest is due to attack of insects, pests and fungi. Many destructive forest diseases are due to parasitic fungi, rusts, viruses and nematodes. Young seedlings are destroyed due to attack of nematodes. Many diseases such as heart rot, blister rust, oak wilt, phloem necrosis and Dutch elm diseases etc. are common in the forest. The forest diseases can be controlled up to some extent by following methods :

1. By eradication of host
2. By using suitable antibiotics
3. By DDT Spray
4. Sterilization
5. By using resistant varieties.

Besides above, following measures of forest management have been recommended :

1. Reforestation
2. By improving the quality of timber
3. By converting wasteful cutting into quality yield harvesting
4. By increasing forest protection
5. By increasing forest area
6. By developing fast growing trees

7. By controlling harmful forest agents
8. By developing the better varieties
9. By using disease resistant varieties.

In India about 75 million hectares area is occupied by forest alone which is about 23 per cent of the total land. In India forests have not so far played a significant role in improvement of economic condition of the country. Proper scientific management, conservation and utilization of forest wealth is likely to increase their resource value and utility in the future. At present there is an urgent need to conserve the existing forest resources and to expand the forest area. The most important task is to restore the vegetation cover, which is destroyed through our false policies. New forests and wood lots should be created to meet the daily demand of fuel and fodder and to provide more habitat for wild life.

The National Commission on Agriculture is giving serious thought to the problem of deforestation and recommended introduction of "Social Forestry" *i.e.*, to create multipurpose village wood lots in rural India. Social forestry may be defined as an additional aid to wild life conservation. According to K. M. Tewari (President, Forest Research Institute, Dehradun) "Social forestry is a concept, a programme and a mission which aims at ensuring ecological, economic and social security to the people, particularly to the rural masses especially by involving the beneficiaries, right from the planning stage to the harvesting stage. It aims at mixed production system of wood, fibre, fodder, grasses, fruits and other raw materials for self-consumption and cottage industry."

Different components of social forestry programme are :

1. Protection and afforestation of degraded forests in the vicinity of habitations.
2. Creation of village wood lots on community lands and government waste lands.
3. Block plantation.
4. Agro-forestry (trees along with agricultural crops) on marginal and sub-marginal farm lands.
5. Tree planting around habitation area, field boundaries and Pasture development.
6. Tree planting in Urban and Industrial areas for aesthetic purposes, purification of polluted air, absorption of CO_2, release of O_2 and control of noise pollution.
7. Control of erosion by planting trees or shrubs.
8. Strip plantation along road sides, canals and rail lines.

If above programmes are carried out effectively the basic needs of rural people such as fuel, fodder, fibre and timber could be met easily and ensure ecological security like protection against wind, erosion, polluted water and air and availability of desired habitat for the wild life. Social forestry can play a significant role to check flood and drought which affect 34–68 million hectares of land respectively in India (Dr. K. K. Mahajan, Deptt. of Environment, Govt. of India).

Wild Life Resources

In the modern sense according to Dr. Mahajan (1961) wild life means, life in any form (plant/animal) existing in natural surrounding. Wild life provides recreational and economic benefit to man. Recreational and economic benefits are closely related to each other. For instance fishing and hunting provide entertainment and economic benefit to man.

Wild life includes 350 species of mammals, 1200 species and 2100 sub-species of birds and more than 20,000 species of insects. In its diversity of life forms India is the second largest country in the world.

The causes of decline of wild life in India are many. Wild elephants were captured and trained for use in war. Rhinos were killed for making shield. Rulers of princely states indulged in killing of wild animals as their hobby. Forests were cleared for development of agriculture, industry and other developmental projects. Wild animals were mercilessly killed resulting in decline of their number and facing extinction now.

Today wild life species are gradually disappearing and their number is becoming reduced. Many species of wild life have become extinct or are in the way of extinction. Uptill now 106 species of animals and 139 species of birds have become extinct due to climatic and geographical changes or by hunting of the man and about 600 species of animals and birds are going to be extinct if they are not protected. Today the lion is limited in number. The number is around 200 in the Gir forest of Gujarat. The rhino existed in Indus valley in the vicinity of Mohenjo-Daro some 5000 years ago. The rhinos are now found in certain parts of Nepal, West Bengal and Assam.

The number of tigers are also very limited. According to 1972 census the tigers were 1827 in India.

The protection of wild life from unwanted destruction is called conservation. Conservation is an intelligent and judicious management of resources, towards their optimum utilization without depleting the basic stock.

Well planned projects for conservation of forests and wild life are executed with the aid from W.L.F. (World Life Fund), the International Union for Conservation of Natural Resources. Through the Convention on International Trade in threatened and endangered species of wild Fauna and Flora a number of species such as hispid hare, pigmy hog, lion, tiger, rhino, thamin and great median bustard have been saved. In 1973, a project for saving tiger was started and yielded very satisfactory results. The number of tigers increased considerably and it has become difficult to maintain them in their reserves. They have started killing rural population and their cattles outside the limits of Corbett and Dudhwa National Park of

U. P. All life forms created by nature are directly or indirectly dependent for their survival on other life forms.

Now following steps of wild life management have been taken into consideration :

(i) **Conservation of habitat**. The first step towards conserving the remaining wild life is to conserve the different habitats in which they live, for example, tropical forest, pine forest, wet land swamp, shrubs and grass lands need protection. The conservation of wild life also depends on the conservation of other resources. The best way is to preserve wild life that both the habitat and animals are preserved in wild life sanctuaries and National Parks.

(ii) **Species Preservation**. The animals which are rare should be protected from being hunted. Generally these animals are hunted for recreation or to get various parts from their body as teeth, skin, horn or meat. Killing or hunting can be banned by legislation, or by the protection of the animal by the forest department. If there is no proper preservation of the wild life the animals may disappear in future due to unrestricted human predator.

(iii) **Introduction of exotic species**. Introduction of exotic species is another method of wild life development and management. They may be brought over to serve as predators in controlling some pest or add colour to the wild life community.

(iv) **Predator Control**. Now ecologists consider that predators play an important part of the ecosystem. Predators may also serve a useful role in keeping the primary population within limits. Lack of predators results in population explosion.

(v) **Legislation of Wild Life**. Nowadays government is thinking to make an Act against hunting of wild life. Nowadays hunting of certain wild animals has been banned such as python, elephants, lion, leopard, black buck, crocodile and gharial etc.

Water resources

Water is most important for the life of living organism such as plants, animals and man. It is also essential for agriculture, industries, drinking and many other purposes The water of atmosphere reaches the earth surface through rain water and from earth surface it reaches the atmosphere through evaporation and transpiration. Thus continuous circulation of water from earth to atmosphere and vice versa is maintained by nature. This is called water cycle. It is not continuously moving but remains either within the earth crust or on the surface, or as the atmosphere. Water occurs in three forms solid, liquid and gas.

It has been calculated if the earth were smooth, the ocean would be sufficient to submerge the entire world to a depth of 800 feet. According to Kalinin and Bykov (1969) there in total water earth is $1{\cdot}46 \times 10^9$ cubic kilometers, 93 per cent in the ocean and 4·1 per cent on the earth, 2·0 per cent in the glaciers and 0·052 per cent in lake, river and atmospheric moisture.

Water is most important component of our ecosystem. Washing, cleaning, extinguishing and flushing are important functions performed by the water. It is most important component for power industry. It is raw material for photosynthesis and numerous products. Man needs water for survival, drinking and many other commercial purposes.

Man can live few days without food but can not live without water. Our body contains 100 pounds of water. There are many functions of water in the body. It serves as a solvent. It promotes chemical activity. It serves as transportation medium for nutrients, hormones, enzymes. Man will die if he loses more than 12 per cent water content from his body. Most organisms regardless of body size, food habits or habitat have a high water content. The water content in corn is 70 per cent.

Sometimes due to severe dry condition drought is produced. It is due to lack of rainfall of sufficient duration and causes widespread damage to crops. The more severe droughts result in reduction in ground water levels, heavy mortality of aquatic wild life, extensive destruction of grasses, pasture and crops. Top soil is desiccated and leads to erosion. It also results in high incidence of forest fires.

Flood is the result of excess rain and uneven distribution of water and man has suffered a heavy loss from the damage caused by flood. In some parts survival becomes difficult. Fertile soil of upper surface is carried away and lost, thus agricultural economy is reduced. It is difficult to control the flood but it can be prevented up to a limited extent. Flood can be controlled by protecting the watershed, construction of dams and prevention of human encroachment on flood plains.

It has been estimated that there is about annual production of water through rain 3,70,000 cubic kilometer and total water which is used annually is about 10,000 cubic kilometer. Still there is shortage of water and there are two main reasons of its shortage. Firstly, there is no proper utilization and distribution of water and secondly water quality is deteriorated.

This problem can be solved by recycling of water at local level.

Today there is a great problem about water pollution. Many of the wastes of human society are disposed of in the river, lake and ocean and water becomes polluted which is not fit for drinking and other purposes. The sewage of big cities is often drained into rivers which is most dangerous. Reduction of oxygen and presence of wastes affect the fish and aquatic population. Such water is also consumed by man for various purposes. This causes diseases like cholera, dysentery and hepatitis etc. Other effects are :

1. Addition of poisonous substances
2. Addition of suspended particles
3. Reduction of oxygen
4. Heating of water.

Waste water from municipalities, sanitoria and tannings discharged in the rivers, canals and lakes etc. carries many sources of bacteria and other microbes which cause diseases to man and animals like cholera, typhoids and many skin diseases. These are transmitted through polluted water.

The water conservation is very important for agriculture, industries and for urban population. This can be done by following methods :

1. Proper distribution and utilization of water
2. Proper drainage
3. Proper storage
4. Storage by dams
5. Pumping of ground water
6. Flood control.

Soil Resources

The top layer of the earth is called soil which is very fertile because it contains minerals and humus. Soil is natural habitat for plants and animals. It provides water and nutrients to the living organisms. Knowledge of soil is helpful in agricultural practices, such as cultivation, irrigation, artificial drainage and use of fertilizers. It is also important from geological, petrological, minerological and paleobotanical points of view.

Soil is much damaged through tree cutting, running water and wind. It has been estimated that from 1959 to 1969 there was a loss of 16·9 lac hectares of land. The soil is subjected to a continuous and simultaneous depletion and addition of soil resources. The important factors which make the soil less fertile are leaching, cropping and soil erosion. The damage of soil can be prevented by plants in the following ways :

1. Trees check the force of strong wind which prevents the fertile soil to move from its original place. Thus trees act as windbreakers.

2. Roots of plants anchor the soil firmly. This prevents the soil erosion from rain and flood and fertile soil is checked from damage.

3. Plants and animals when die are decomposed by bacteria and fungi, which increase the fertility of soil.

4. Soil fertility can be restored by supplementing manures and fertilizers.

The details of soil conservation are described in soil erosion and soil conservation and soil fertility chapters of this book.

Now man is cutting trees for his habitation, cultivation and timber use and indirectly soil is spoiled. Destruction of forest has caused not only soil erosion but climate is also affected. Oxygen supply in the atmosphere becomes reduced and many other problems have resulted. It has been estimated that 1 inch spoiled soil takes about 900 years to restore the fertility of soil.

Marine Resources

The ocean comprises nearly three-fourth of earth's surface. Ocean has been the source of many needs of man from the time immemorial. The rapid growth of human population and the advancement of industrialization have exerted great pressure on the ocean resources and the ocean environment. According to recent data, about 35 km^3 of sewage and 3·5 km^3 of industrial wastes are released annually into the coastal waters of India. In addition, the offshore oil installations have added another stress on the ocean environment. The recent exploration of the oil well in the "Bombay high" invoked a great concern about growing dangers of pollution of the ocean waters. The increasing exploitation of certain economically important red and brown algae without any proper conservation and indiscriminate mining of coral stones for industrial purpose eliminating the substratum for the sea algae to grow are the serious problems which need our immediate attention.

Land resources are depleting at tremendous rate and in view of this, man has started thinking to exploit the oceanic resources. Navigation and shipping is an important use of ocean. Besides this, sea-beds and ocean floors are now known to contain larger reserve of fuel minerals such as coal, petroleum and metallic minerals. The edible fishes and marine aminals are in abundance. Certain areas of west coast of India are rich in petroleum and oil. Efforts are being made to modernise marine fishing technology in India.

Sea weeds which are generally considered a nuisance could offer a solution as an alternative source for food because of their high nutrition value. Sea weeds can be used as a food, pharmaceuticals, textile and agar. Algin, carrageenin are the important substances extracted from seaweeds and used in icecream, malted milk, cheese, chocolates, puddings etc. Besides these, sea weeds are also used as food, fodder, fertilizer and biomass. It has been estimated that the total annual yield of sea weed in the country is 50,000 tons and it may reach to one lakh tons if all the precautions are taken in utilizing the resources. Planktons (Phyto-planktons and zooplanktons) provide rich nutrition. Scientists are now interested in evolving methods of directly converting the plankton into food so that the world's food supply may be considerably enhanced and utilized for overpopulated world.

Mangrove forests are more common in the sea coasts. These act as guard. The reclamation of saline soil by enriching the coastal soils with organic matter thereby facilitating other plants to grow and the control of soil erosion in coasts are the main contribution of mangrove forests. It is a matter of great concern that these forests are damaging at an alarming rate exposing sea coasts to the tides and cyclones. An important step in this direction is to protect the slow growing mangroves by fast growing trees along with coasts and thus providing an alternate supply of fuel to the people.

It is now a well established fact that the ocean surface of 1 cm thickness known as surface micro-layer plays a crucial role in air-sea interaction. Detailed study of this layer is important in meteorology, agriculture and pollution. This micro-layer transfers not only energy and water vapour but also rich nutrients like N.P.K. into the atmosphere. Oil spills and other pollutants over the ocean, concentrate in this micro-layer and finally enter into the food chain through marine organisms.

Other uses of sea in the future are :

(1) Manufacture of sea planes.

(2) Floating cities on the surface of the ocean.

(3) Cultivation of sea weeds as an alternative source of food and energy.

(4) Production of power from sea tides.

(5) Fresh drinking water by modern methods of desalination.

(6) Study on origin of monsoons and avoid recurrent droughts.

(7) Rich potential of off-shore oil.

(8) Mineral deposits of oceans.

The task of harnessing the potential of ocean resources for development purposes is of great importance, we should pay our attention to the development of necessary resources of ocean when our land resources are in short supply. Now much awareness is needed by the National government and International agencies including United Nations about conservation of ocean's wealth. While studying the ocean environment, it is necessary to understand about the physics, chemistry, biology and geology of the ocean. It is essential that in ocean-oriented programme, lawyers, economists, businessmen, scientists and social workers should be involved in the decision-making policies.

Food and Agriculture resources

Man needs energy for his various activities as movement, growth, respiration, reproduction and many others. For physical and metabolic activities energy is essential. In our body many biological activities are going on which are collectively called metabolism. These activities need energy which is obtained from food. A food is a substance which is mixture of nutritive and non-nutritive substances. The main components of food are carbohydrate, fat, protein, minerals, vitamins and water. These are supplied through cereals, pulses, oils, eggs, sweets, milk, meat, cheese and fruits.

Food is classified mainly on the two bases :

1. On the basis of work.
2. On the basis of nutrients.

On the basis of work food has been classified into three groups :

(*i*) **Energy-giving food** : This includes fat and carbohydrates. This food provides high energy which can be obtained from cereals, sugars, animal fats, vegetable oils etc.

(*ii*) **Body-building food** : This includes protein and minerals. These are found in pulses, milk products such as cheese, fish, meat, eggs etc. These provide energy which is essential for body-building, growth and repairs of tissues.

(*iii*) **Protective food** : This food protects the body from different diseases and regulates different functions of body. This food is rich in minerals, salts and vitamins. This type of food is available from green vegetables, fruits, milk and eggs.

On the basis of nutrients food may be in the form of carbohydrates, protein, fat, vitamin and minerals.

Our food contains different nutrients and each nutrient performs its own function but we need protein, carbohydrate, fat, minerals, vitamins and water in proper proportion. Deficiency or excess of any of these causes disorder in the body. Thus a balanced diet is that which provides proper amount and proper proportion of nutrients. Bālanced diet of an average adult man is given below in the table 1.

Table 1. Blanced diet for adult man

Food	*Weight*	*Food*	*Weight*
Cereals	400 gm	Milk and milk products	284 gm
Pulses	85 gm	Flesh (meat)	125 gm
Other vegetables	85 gm	Sugar	57 gm
Root vegetables	85 gm	Fat (Ghee, oil)	57 gm
Fruits	85 gm		

A healthy youngman who does physical work needs 3,000 calories daily. Such diet should contain 90 gm protein, 90 gm fat, 450 gm carbohydrate and sufficient amount of vitamins, minerals and water. Nutrient value of different foods is given below (Table 2).

Table 2. Nutrient value in different sources of food

Food	*Protein*	*Fat*	*Carbohydrate*	*Salt*	*Water*
1. Milk	3·5	3·7	4·9	0·7	87·0
2. Meat	15·1	14·7	—	0·8	69·4
3. Fish	16·0	5·0	—	1·0	78·0
4. Wheat	11·4	1·0	75·0	0·5	12·0
5. Rice	1·7	0·4	76·0	0·4	15·5
6. Maize	8·4	4·7	72·0	1·3	13·6
7. Potato	2·0	0·1	21·0	1·0	75·9
8. Sugar	—	—	100	—	—
9. Egg	13·2	10·3	—	0·9	75·6

Today food demand is increasing rapidly due to overpopulation and increased consumption of food. Effort is being made to increase food production all over the world. According to F.A.O. "all the good lands in the world being cultivated and even marginal lands will be exhausted by 1985". In many parts of the world a number of ecologically unsound practices are being applied that have resulted in short-term production gains at the expense of long-term food output. Overgrazing, burning of vegetation, deforestation and expansion of agriculture are some known examples.

Most of us get food mainly through agriculture. Cultivation of crop plants is done through two methods :

1. **Shifting cultivation**. This is very old agricultural practice. In this case natural ecosystem is manipulated and is done in the limited area for short period. In this system cultivated area is temporarily covered by wild vegetation. This type of cultivation is generally practised in the mountain area where the rainfall is heavy. Most of the tribal population depends primarily upon shifting cultivation.

There are many defects of shifting cultivation. Natural ecosystem is disturbed, yield is decreased due to uncared cultivation and crops are infected with many diseases.

Following control measures have been taken regarding shifting cultivation :

(*i*) Proper management of settlement of tribal population should be made because migration of tribal people needs shifting cultivation and facilities of farming should be provided to them.

(*ii*) Now agriculture should be altered with silviculture scheme so that land use involves an integrated programme of agriculture, horticulture and forestry.

(*iii*) Annual crops should be replaced with perennial crops.

(*iv*) Rotation of crops with forest and field crops has given better results in the slopy area of hills.

2. **Sedentary cultivation**. In this case natural ecosystem is permanently changed. In this system previous plants are removed and domesticated plants are grown. In dry places soil is gradually depleted with minerals and nutrients which may be restored by adding fertilizers or green manures.

Deforestation, overgrazing, fire and deserts are the results of mismanagement of agriculture. Soil erosion and lowering of water table are also the results of climatic and geological factors.

Extension and intensification of agriculture are the important steps to increase the yield which have solved the problem of shortage of food and malnutrition. For extension we need better irrigation, improved varieties of seeds, agricultural instruments and better roads. Flood control, proper drainage, erosion control-mechanisation, fertilizers, pesticides and improved varieties of seeds are the important steps to increase yield.

Besides these methods, we should select some alternative sources of food. Deficiency of protein should be compensated from animal source rather than plants. Fishes and eggs are the important sources of protein. Now-a-days everywhere fisheries departments have been established to meet the high demand of fishes. It also gives enough foreign exchange. Poultry breeding programme is very significant now-a-days because the consumption of eggs is increasing tremendously day by day. Under poultry, chickens and ducks are included. Some algae, mushrooms, grasses and some aquatics are also rich in protein contents which are consumed by man.

There is a tremendous loss in yield due to plant diseases which are caused by bacteria, virus, mycoplasma and pests. It has been estimated that there is 15—20 per cent loss in yield due to plant diseases alone. Sometimes sudden outbreak of a disease can cause severe loss in the production. Plant diseases are the main problem and barrier to crop production. The damage caused by pests is tremendous and sometimes it is irreparable. There are many agents which cause the diseases to crop plants.

Efforts for Conservation of Natural Resources at National and International level

Life of man, his development and development of nation depends on the natural resources. Shortage of these resources will lead to poverty of nation. Man is exploiting the various natural resources at faster rate without thinking its serious consequences. Man is using tremendous amount of coal, petrol and natural gas. Considerable amount of this non-renewable energy reserve can be saved or reduced by minimizing air pollution resulting from burning of petroleum products. Increasing use of nitrogenous fertilizers and pesticides in agriculture has increased the problem of water pollution. Deforestation has produced the soil erosion, loss of soil fertility and floods. Industrialization and urbanization have created the problems of waste disposal, sanitation and healthy air.

Now man has started thinking to realize about the natural resources. He wants to minimize the indiscriminate use and abuse of environment for best possible use of land and sea reserves. The success can be achieved of above objects at global level by national and international efforts. For this national and international legislation is needed. To study this several governments of different countries have set up a closely related organisation at international level. The International Union for Conservation of Nature and Natural Resources (I.U.C.N.N.) was established in 1948. The head office of this organisation is in Switzerland. Similarly, another sister organization has been set up in the name of World Wild Life Fund (W.W.F.). The World Wild Life Fund deals with :

(*i*) To raise the funds for conservation.

(*ii*) To make the people aware of various conservation methods.

(*iii*) To protect the wild animals from hunting.

(*iv*) To develop national parks for their protection.

There are 24 branches of W.L.F. including India. Besides these, Indian Board for Wild Life was created in 1952. Under this, from 1 to 8th October a wild life week is celebrated throughout the country W.L.F. has spent about Rs. 160 million on different conservation projects in different countries. These projects include the breeding of rare species. The construction of national parks and pressurising governments to pass legislation necessary for conservation are also objectives of these organisations. The branches in India were established in 1969 to support many valuable projects. Among these projects "Great Indian Bustard" and "Nilgiri Tahr" are significant which have established a "Madras Snake Park". 'Tiger project' has been undertaken jointly by the Government of India.

Government of India is very careful and making serious efforts to preserve our natural resources. Now every year from 1st October to 8th October, a *Wild Life Week* is celebrated all over the country. Now government has some legislation against hunting of certain wild animals, and cutting of trees. Hunting of tiger, lion, deer and elephant has now been banned. The trade of export of tiger and panther skins, crocodile skin and rhino horn has been restricted.

Reforestation, replanting and construction of national parks are being seriously undertaken all over the country. In India there are several national parks and wild life sanctuaries in the country. The "Corbett National Park" and "Dudhwa National Park" in U.P. "Kanha National Park" in M.P. are important where wild life animals are protected. Similarly "Gir Sanctuary of Gujarat" is an important harbour for lion. "Bharatpur Water Bird Sanctuary" in Rajasthan is one of the most beautiful sanctuaries of the world.

Environment management is another solution of depletion of resources. We know that the environment is deteriorating due to industrial pollution, toxic chemicals, depletion of natural resources and air pollution. Many of us, probably do not understand the environment management due to our ignorance or deliberate negligence. According to a project "The Limits to Growth" which was summarised by Jolly, 1977 in a symposium held by Government of India at New Delhi current trends are given below :

1. If the present growth trends in the world population, industrialization, food production and natural resource depletion continue unchanged the limits to growth on this planet will be reached within the next hundred years.

2. It is possible to alter these growth trends to establish a condition of ecological economic stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on earth are satisfied.

3. If the world's people decide to strive for this second outcome rather than the first, the sooner they begin working to attain it the greater will be their chances of success.

If above programmes are carried out effectively it would ensure that basic needs of the common people could be met in respect of fuel, fodder, fibre, timber on one hand and ensure ecological security on the other hand.

QUESTIONS

1. What do you know about conservation ? What are main reasons of depletion of natural resources ?
2. What are different kinds of natural resources ? How their misuse can be checked ?
3. Write about the following :

   Mineral resources, wild life, social forestry, food resources.
4. What are various steps for conservation of natural resources at national and international level ?

SOIL SCIENCE

15

THE SOIL

The word soil is derived from a Latin word *'solum'* meaning earthy material in which plants grow. The study of soil is known as *Soil science* or *Pedology* (Pedos=earth) or *Edaphology* (edaphos= soil). The study of soil is important in many respects. Soil is natural habitat for plants and animals. It provides water and nutrients to the living organisms. Knowledge of soil is helpful in agricultural practices, such as cultivation, irrigation, artificial drainage and use of fertilizers. It is also important from geological, petrological, minerological and paleobotanical points of view.

The earth is, more or less, spherical and its surface is highly irregular marked by deep oceans, high mountain ranges and plains in between. The internal composition of earth is not known exactly. According to a generally accepted interpretation, the earth has three zones, *viz.*, core, mantle and crust (Fig. 15·1). The core is the central fluid or vapourised sphere having diameter of about 2,500 kms from the centre and is possibly composed of nickel-iron (Urey, 1952). The mantle extends about 2,900 kms above the core. This is in molten state. The outermost solid zone of the earth is called crust which is about 8 to 40 kms above the mantle. The crust is very complex. We live on its surface. Soil developed from the pre-existing rocks, the regolith of the crust. Here soil means the *loose, friable, unconsolidated top layer of the earth crust*. The soil is differentiated into several layers or horizons which can be distinguished from one another by their colours, textures and other characteristics. It contains water, gases, complex minerals, organic substances and microorganisms. The dead remains of plants and animals are degraded by microorganisms and after degradation a number of organic substances, generally called humus, are contributed to the soil. The mineral component of the soil is derived from the rocks.

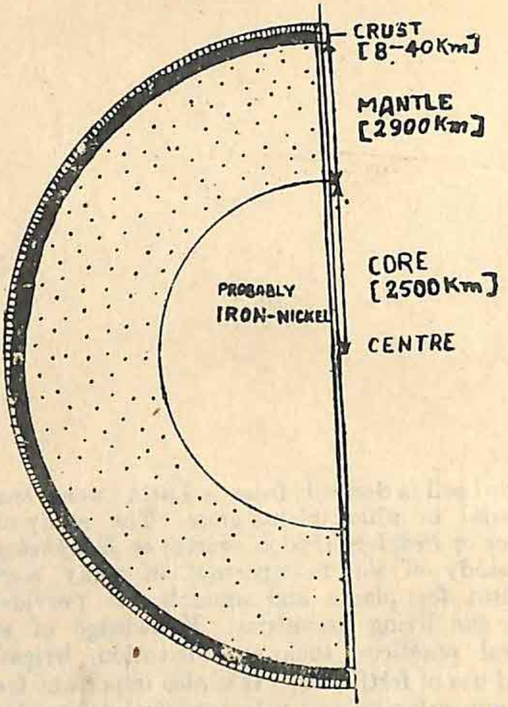


Fig. 15·1 —Diagram of the supposed cross section of the earth.

Definition of soil

Soil may be defined as "the part of earth crust in which humus is present".

According to Daubenmire, R. F., "soil is the upper part of earth crust in which plants are anchored." He defines soil as weathered superficial layer of earth crust with which are mingled living organisms and products of their decay.

According to Hilgard, 1917 (American school), "it is more or less loose, friable material in which, by means of their roots, plants may or do find a foothold, nourishment as well as other conditions of growth."

According of Raman, 1928 (German School), "soil is the upper weathering layer (i.e., layer subjected to physical and chemical changes) of the solid earth crust."

Joffe and Marbut, two well known American soil scientists, have defined soil in the following way : "soil is a natural body developed by natural forces acting on natural materials". It is usually differentiated into horizons of minerals and organic constituents of variable depth which differ from the parent materials in morphology, physical constitutions, chemical properties, composition and biological characteristics."

According to Russian school, "soil is natural body differentiated into horizons of usually unconsolidated minerals and organic constituents of variable depth."

According of Wadia (1945), "soil is the topmost layer of earth crust capping the rock." It is natural body of variable thickness, composed of disintegrated rock materials together with variable proportions of organic matters, generally differentiated into zones or layers and mostly unconsolidated.

In brief, soil can be defined as that region on the earth surface where geology and biology meet each other.

Components of soil

The soil is made up of the following components :

(1) Mineral particles,

(2) Dead organic matter or humus,

(3) Soil atmosphere,

(4) Soil water,

(5) Biological system or soil microorganisms.

(1) Mineral Components

The mineral constituents of the soil are derived from the parental rocks or regolith. They may be found in the form of particles of different sizes ; from clay (.0002 mm. or less in diam.) to large pebbles and gravels. The minerals represent about 90% of the total weight of the soil. Important elements which are found in compound state are Oxygen, Si, Fe, Al, N, P, K, Ca, Mg, C, H *etc*. In soil, nitrogen comes from atmosphere in the form of nitrogen salts.

(2) Organic Matter or Humus

Besides inorganic minerals, some organic residues derived either from dead remains of plants and animals or through metabolic activities of living organisms are present in the soil. When the plants and animals die, their dead remains are acted upon by a number of microorganisms and are finally degraded or decomposed into simple organic compounds. A product of this microbial decomposition is humus which is a dark coloured, jelly like amorphous substance, composed of residual organic matters not readily decomposed by soil microorganisms. The process of humus formation is called humification. The chief elements found in humus are carbon, hydrogen, oxygen, sulphur and nitrogen. The important compounds found in it (humus) are carbohydrates, phosphoric acid, some organic acids, fats, resins, urea, *etc*. Tree litter (very little decomposed dead matter) also contains some inorganic substances as lime, potash, Mn., Mg, silica, Cu, Al, Ca, Na, K, *etc*. Humus is a dynamic product and is constantly changing because of its oxidation, reduction and hydrolysis. Hence, it has got no definite chemical composition. It has got much carbon content and less nitrogen.

Humus is not soluble in water. It is present in soil in the form of organic colloids. The amounts of humus in different soils vary greatly. Humus percentage in the soil is affected by climatic and biological factors. It is less in arid soils and very high in humid soils. In the top layer of the soil, humus quantity is greater than that in the deep layers. In dark humid areas which are thickly covered with vegetation, the humus may be found in the following three stages of degradation.

(i) The top floor is covered with dead organic parts showing low degree of decomposition. These poorly decayed dead parts of plants form *litter*.

(ii) Below the litter may be found a layer of partially decomposed organic matter which is known as *duff layer*.

(iii) When the duff is decomposed completely into organic substances, the decomposition products, generally called *leaf moulds*, are accumulated below duff layer.

Sometimes under anaerobic conditions, the dead remains are not at all acted upon by the microorganisms. Accumulation of such undecomposed organic remains is termed as *peat*.

Humus plays many important roles in the soil, such as :

(a) It makes the soil fertile.

(b) It provides nutrients to the plants and microorganisms.

(c) On complete decomposition, it forms several organic acids which serve as solvents for soil materials. Thus humus increases the availability of minerals in dissolved state to plants.

(d) Because it is porus, it has got high capacity for retaining water.

(e) Humus makes the soil porous, thus increases the aeration and percolation which make the soil more suitable for the plant growth.

(f) It also acts as weak cement thus binds the sand particles.

(g) Presence of humus in the soil increases the rate of absorption in plants.

The factors which influence the rate of humifications are outlined below :

(i) Nature of plants, animals or soil organisms.

(ii) Rate of decomposition.

(iii) Temperature (increase in temperature up to a certain limit increases the rate of humification).

(iv) Aeration and moisture. These *increase* the rate of humification.

4. Soil Atmosphere

Gases found in soil profiles are said to form the soil atmosphere which is one of the most important components of the soil. The spaces between soil particles *and soil organisms* are called pore spaces. These are filled with **moisture** and air in varying quantities which account for approximately half of the total volume of soil. In dry soils, percentage of moisture is lesser than that in wet soils.

The soil atmosphere contains three main gases, namely, oxygen, carbon dioxide and nitrogen. In the atmosphere, oxygen is 20%, nitrogen is approximately 79 per cent and carbon dioxide is ·15 to ·65 per cent by volume. In the cultivated land, percentage of CO_2 is much higher than that of atmospheric CO_2, but oxygen content in such soil is poorer than the percentage of oxygen in atmospheric air. Oxygen of soils is absorbed by plant roots and soil micro-organisms in respiration and CO_2 is given out which accumulates in spaces. The amount of CO_2 increases with the increase in depth of the soil due to decomposition of accumulated organic matter and abundance of plant roots. Heavy accumulation of CO_2 in the soil is harmful in the plant growth. Presence of oxygen in the soil is important in the sense that it helps in the process of breaking down of insoluble rocky mass into soluble minerals and also in the humification (a process in which insoluble minerals and organic nutrients locked up in the dead remains of plants and animals are converted into soluble forms). The accumulation of soluble nutrients in the soil makes it more productive. If the soil is deficient in oxygen, the rates of microbial activities are slowed down and may be eliminated. Under such conditions, several undesirable processes, such as evolution of nitrogen, methane, accumulation of sulphides, ferrous, manganous ions and organic inhibitors and so many other processes may come into play which may be injurious to the plants.

The important factors which bring about changes in the soil atmosphere are temperature, atmospheric pressure, wind and rainfall. Temperature and atmospheric pressure cause expansion and contraction of the soil air. Wind helps the soil in sucking the air in and rain water displaces the soil air. Any considerable change in the soil atmosphere affects the size and function of microflora and other biological populations.

4. Soil water

Soil water plays very important role in the plant growth. Plants absorb a small quantity of rain water and dew directly from their surfaces but most of water absorbed by them comes from the soil.

Soil water maintains the soil texture, arrangement and compactness of soil particles. It is good solvent for minerals and it makes the concentration of nutrients low so that nutrients may be absorbed by plants easily. Water affects the plant growth and other physiological activities. In plant growth, water forms a major part of the plant itself. It is essential for the process of photosynthesis, it maintains the turgidity of the plants and acts as a medium by which mineral salts essential for plant growth enter the plants from the soil. In brief, water regulates the physical, chemical and biological activities in the soil.

Water in the soil comes mainly through infiltration of precipitated water (rain, sleet, snow and hail) and irrigation whereas it is lost from the soil chiefly through evaporation, percolation, stream flow and transpiration.

The quantity of water available in the soil varies from place to place. The amount also depends upon the quality of soil. In loamy, silty and clay soils, the amount of water is greater than that in coarse sandy soil. Water is held in the soil in the following forms :

(*i*) Gravitation water,
(*ii*) Capillary water,
(*iii*) Hygroscopic water,
(*iv*) Water vapour,
(*v*) Combined water.

(i) Gravitational Water

After complete water saturation of soils the excess water displaces air from the pore spaces between soil particles and percolates downwardly under gravitation influence and finally it is accumulated in the pore spaces. This excess water is called *gravitational water.* The amount of water held in the soil when all pores are filled and when drainage is restricted is *maximum water holding capacity.*

When the gravitational water percolates down and reaches to the level of parental rock it is called *ground water.*

(ii) Capillary Water

The amount of water present around the soil particles at saturation stage, when gravitational water has drained away through capillaries or channels, is called *capillary capacity* or *field capacity* and the water which is held by surface tension and attraction force of water molecules as thin film around soil particles in the capillary spaces is called capillary water. It moves in the direction where capillary tension is more.

(iii) Hygroscopic Water

Water which is absorbed on the soil particles and held on the surface of soil particles by forces of attraction and cohesion of its molecules is called hygroscopic water.

(iv) Water Vapour

This is the water present in the soil atmosphere in the vapour form.

(v) Combined Water

It is water of chemical compounds held by chemical forces of molecules (as for example, $CuSO_4.5H_2O$). It can be driven out from the compounds only at bright red heating.

Water requirement of plants varies from individual to individual. Some absorb large quantity, while some others require very small quantities of water for their normal growth. A major fraction of total water absorbed from the soil is transpired by the plants and only a small quantity of it enters the composition of protoplast. The availability of soil water to plants depends primarily on its diffusion pressure deficit, often termed the *soil moisture stress.* The total of all the forces which the plants must overcome to take up water from soil is called soil moisture stress.

Water lost from the soil surface by evaporation and through absorption by plants is replaced by rise of capillary water from root zone. The continuous loss of water may finally result a stage where water content of the soil becomes so poor as it (soil) cannot supply water to growing plants rapidly enough to maintain them turgid. Under such conditions, permanent wilting occurs in the plants. At permanent wilting stage, the percentage of moisture in the soil is termed as *wilting coefficient* or *permanent wilting percentage* (Fig. **15.2**

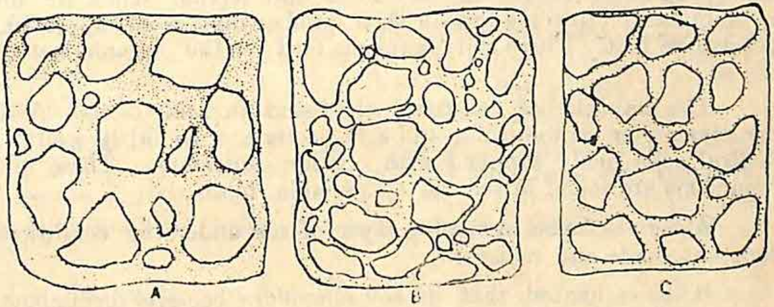


Fig. 15·2—Soil water, A. saturation point ; B. field capacity ; and C. wilting point.

The difference between field capacity and wilting coefficient is termed as maximum available water and the water content of the soil at any time over and above the wilting coefficient is referred to as *available water*. The amount of water to apply to a soil at the wilting point to reach the field capacity is called the *available water capacity*. It need not be emphasized here that the actual moisture content of a soil has little meaning in respect to plant growth unless (i) the field capacity and (ii) the permanent wilting percentage of the soil are also known. Water contents above field capacity displace so much of the soil air that the plant roots usually suffer from inadequate aeration and serve to be detrimental. Although plants usually continue to absorb water in the soil drier than permanent wilting stage, absorption is too slow to replace water losses and the resulting water deficit causes cessation of growth and finally results in death from dehydration.

The moisture at the field capacity is held with a force of one-third atmosphere and that at permanent wilting stage is held with a force of 1·5 atmosphere.

5. Biological system of the Soil or Soil microorganisms

Organisms present in the soils are called soil organisms. Important groups of soil organisms are given below :

Soil Flora	*Soil Fauna*
1. Bacteria	1. Protozoa
2. Soil fungi	2. Nematodes
3. Soil actinomycetes	3. Insects and mites
4. Algae	4. Rodents and earthworms
5. Root, rhizoid and rhizome bearing higher plants.	5. Burrowing vertebrates

Many of these soil organisms are stable, many are mobile, but some are held in the colloidal films of the soil particles. Protozoa, mites and insects are example of moving organisms. They move in or on the surface of soil in search of food. Earthworms by their burrowing habit make the soil loose and fertile. They are found in abundance. In some forests their number may reach up to 10,000 per square foot. These soil organisms feed on the organic matter of the soil.

The majority of soil fungi are found in acidic soils. Actinomycetes prefer saline soils and soil bacteria grow fairly well in the neutral soils richly supplied with organic nutrients. These microorganisms are found in the soil at variable depth.

Algae are found in the top layer of soil under the conditions of constant shade and moisture.

It is estimated that in soil microflora bacteria form about 90 per cent of the total population. Fungi and algae together represent one per cent and actinomycetes cover only 9 per cent.

Density of microbial population is actually governed and influenced by climatic conditions and physical and chemical nature of soil and vegetation cover. The greatest amount of microbes (10,00,000 per cu. cm.) is found in the top layer of soil at a depth of 5 to 15 cm. In deeper layer (1·5 to 5 m) individual microbes are found. However, they have been discovered at a depth of 17·5 m in coal, oil and artesian water. It has been calculated that in the ploughed layer of cultivated soil over an area of one hectare there may be from 5 to 6 tons of microbial mass and one gram of ploughed soil contains 1-10 thousand million bacteria.

Role of Soil Organisms

Soil organisms take part in number of processes in the soils. Some of their important roles are as follows :

(1) to decompose the dead organic matter and to increase plant nutrients in available forms ;

(2) production of toxins;

(3) production of growth stimulating substances;

(4) nitrogen fixation in the soil;

(5) mixing of soil;

(6) improvement in soil aeration;

(7) improvement in the aggregation of soil particles or soil binding; and

(8) cause injury to the plants.

(1) **Decomposition of Dead Organic Matter**. A number of soil microbes attack the dead remains of plants and animals and cause decomposition. In the process of decomposition, complex organic matters are converted into simpler organic compounds. Compounds like sugars, starches and proteins are decomposed first in the decomposition process and then cellulose, fatty substances and lastly lignin and woody substances are degraded. Proteins when acted upon by microbes are converted into amino acids, ammonium salts, nitrates and nitrites. Humus, an intermediate product of decomposition process, is formed by microorganism in optimum physical conditions. In the decomposition process, a number of complex mineral compounds are also converted into simpler and soluble compounds. Organic acids and carbon dioxide that are released by decomposition make insoluble phosphates and other unavailable compounds more easily available to plants.

Decomposition of dead organic matter primarily helps in the feeding and growth process of these microorganisms and secondly, increases the nutrient contents of the soil. Bacteria and soil fungi are main agents which bring about the process of decomposition in the soil.

(2) **Production of Toxins**. In the absence of oxygen some soil microbes secrete chemicals, such as, aldehydes, organic acids etc., which may show toxic effects to many plants. Examples of toxin secreting organisms may be found in fungi, bacteria and algae. *Fusarium lini*, which causes wilt of flax (Alasi) secretes HCN, a deadly poisonous substance and *Fusarium udum*, a fungus causing wilt of pigeon pea (*A*rhar) secretes Fusaric acid in the roots of the host plants. These toxic chemicals secreted by fungi may be responsible for causing wilting in the flax and arhar (*Cajanus cajan*).

(3) **Production of Growth Stimulating Substances**. Many soil organisms including soil fungi and bacteria produce growth stimulating substances such as 3 Indol acetic acid, Gibberellins and Gibberellic acid in the soil. *Fusarium* species have been found to secrete Gibberellin, and Gibberellic acid ($C_{19}H_{22}O_6$).

(4) **Nitrogen Fixation**. Many bacteria inhabiting the root nodules of leguminous plants (*Rhizobium*), nitrogen-fixing bacteria, *living free in the soil* (*Azotobacter, Clostridium pasteurianum*), actinomycetes, fungi, purple bacteria and a number of blue-green algae are known to fix free atmospheric nitrogen gas into nitrogenous compounds, such as nitrates and nitrites, etc., and thereby increase the fertility of the soil. It has been established that in each hectare

of ordinary soil every year 25—50 kg of nitrogen are fixed and in cultivated soil and in soil containing legume plants 35 to 60 kg. and 100 to 400 kg of nitrogen are fixed respectively. *Anabaena*, *Nostoc*, *Microcystis* are important nitrogen fixing blue-green algae. De and Fritsch (1938) have found that certain blue-green algae are able to fix 20 lbs. of atmospheric nitrogen per acre in a rice field. They increase the yield of rice from 15 per cent to 25 per cent. Singh, R.N. (from B. H. U.) and Relwani and others have also shown experimentally that some blue-green algae fix nitrogen in the paddy soils.

(5) **Soil Mixing** Many organisms by their mechanical activities help in mixing and weathering of soil. Roots of the higher plants take active part in the disintegration of rocky mass and also make the compact soil loose. Many rodents, insects and earthworms turn over the soil and sometimes also expose the rock surface for physical and chemical weathering. Burrowing animals, such as rodents, bring soil from deeper regions to the surface. The excreta of soil animal is deposited on the surface of soil in the form of casts which increases the fertility of the soil.

(6) **Soil Aeration Improvement**. Soil microorganisms improve aeration of soil. Burrowing worms are also helpful in improving the aeration and percolation.

(7) **Improvement in Aggregation of Soil Particles**. Bacteria, blue-green algae, and some other microorganisms secrete mucilaginous substances which bind the soil particles into soil aggregates.

(8) **Injury to Plants**. Not all the soil organisms are beneficial in their properties and behaviour. Some microbes become parasites of higher plants and cause considerable damage. Nematodes are important animals which cause a number of diseases in plants. Besides these, many soil bacteria and fungi cause many diseases, such as damping off, seedling blight, root rot, mildew diseases in number of crops.

QUESTIONS

1. Define the soil. Discuss briefly the different components of soil.
2. What is humus ? Give an account of composition and properties of humus and mention its important roles in the soil.
3. Discuss the biological system of soil in detail and mention the role of soil organisms in soil.

16

ORIGIN AND FORMATION OF SOIL

Soils are derived from parent rocks by the process called weathering. In the weathering process, rocks are disintegrated and decomposed into smaller pieces by physical, chemical and biological agencies. The products of weathering are called regoliths which are small particles of rock materials. These particles are basic materials which under the influence of pedogenic or soil forming process finally develop into mature soil. C.F. Marbut (1926) states that "a mature soil is one that has assumed the profile features characteristic of predominant soils on the smooth uplands within the general climatic and botanic regions in which it is found."

The process of soil formations from the rocks can be presented as follows :

Consolidated parent rocks ——————→ small particles of parental material or regolith
(weathering)

Mature soil with profile differentiation. ←—————— regolith
(Pedogenesis)

Weathering is the initial stage and the soil forming processes or pedogenic stages come afterwards. Practically no definite line can be drawn where weathering process terminates and pedogenesis takes its way. In fact, both these processes run simultaneously. Weathering processes lead to disintegration or degradation of complex mineral substances that are locked up in the rocks and eventually simple compounds are formed. The pedogenesis or soil forming process, on the other hand, are constructive and are of bio-geochemical nature in which biological influences play important role.

Rock is a chemical mixture in which a number of minerals are locked up in very complex forms. The chemical and physical properties of minerals composing the rock directly govern the properties of the rock. The following are the principal and secondary minerals which occur in the earth crust :

Name	*Chemical Composition*
(A) Primary Minerals	
Quartz	SiO_2
Micioeline Orthoelase	$KAl\ Si_3O_8$
Na-Plagioclase	$Na\ AlSi_3O_8$
Ca-Plagioclase	$CaAl_2Si_2O_8$
Muscovite	$KAl_3Si_3O_{10}\ (OH)_2$
Augite	$Ca_2(Al\ Fe)_4\ (Mg\ Fe)_4\ Si_6\ O_{24}$
Hornblende	$Ca_2Al_2\ Mg_2Fe_3Si_6\ O_{22}\ (OH)_2$
Biotite	$KAl\ (Mg\ Fe)_3\ Si_3O_{10}\ (OH)_2$
(B) Secondary Minerals	
Calcite	$CaCO_3$
Dolomite	$CaMg(CO_3)_2$
Gypsum	$CaSO_4\ 2H_2O$
Apatite	$Ca_5(PO_4)_3\ (Cl, F)$
Limonite	$Fe_2O_3.\ 3H_2O$
Hematite	Fe_2O_3
Gibbsite	$Al_2O_3.\ 3H_2O$
Clay minerals	all silicates

Besides these, there are a number of other minerals also, such as Tourmaline (Borosilicates or Aluminium with alkali metals and iron and magnesium, Rutile (Titanium oxide), Zircon (Zirconium oxide), Gauconite (hydrated silicates of iron and potassium). These minerals are found in very small quantities in the soil.

According to Clark (1924), the major minerals in the earth's crust occur in the following approximate proportion :

Feldspars 58% ; amphiboles and pyroxenes 16% ; quartz 13% ; micas 4% ; and remaining proportion consists of accessory minerals. (Ref : *Data of Geochemistry*. U.S. Geological Survey Bull. 770·1924·)

Rocks are generally classified into three types on the basis of their origin and structure. These are as under :

(1) igneous rocks,

(2) sedimentary rocks,

(3) metamorphic rocks.

(1) **Igneous rocks**. These are formed by cooling and solidification of molten magma or lava which escapes through fissures from the interior of the earth. The solidification may occur at great depths resulting in the *plutonic rocks*, or at moderate depth in the earth forming the so called *intrusive rocks*, or on the surface of the earth forming the *extrusive or effusive rocks*. Extrusive rocks are formed as a result of volcanic activities.

Important igneous rocks involved in the weathering process are Granite, *Basalt*, Gabbro, Diabase, Syenite and Andesite *etc.* They are composed of primary minerals such as quartz, feldspars and biotite, augite and hornblende.

(2) **Sedimentary Rocks**. These develop due to gradual accumulation and *deposition of weathering product of mineral particles* brought by wind or water on the surface of earth. Such rocks are characterised by the presence of distinct sediments or layers in them. Some important examples of sedimentary rocks are lime stone, shale, conglomerate, sand stone, silt stone etc. Calcite, clays, quartz and dolomite are the minerals commonly dominant in them. Sedimentary rocks do not weather as rapidly as the igneous rocks.

(3) **Metamorphic Rocks**. These are formed after transformation of igneous and sedimentary rocks when they are subjected to intense heat and pressure and are influenced chemically by active liquids and gases. Important metamorphic rocks which take part in weathering process are slate (formed from shale), marble (formed from limestone), schist (formed from shale) and quartzite (from sandstone). Dominant minerals are quartz, clays and calcite.

On the basis of their silica content, rocks have also been classified into acidic, basic and intermediate rocks.

Acidic rocks	Basic rocks	Intermediate rocks
Silica content 65-75% Examples : sand stone, granite etc.	Silica content 40-55% Examples : gabbro, basalt, lime stone etc.	Silica content 55-65% Examples : syenite, diorite, andesite etc.

WEATHERING PROCESS

It is a process in which the massive consolidated rocks are broken down into smaller particles and eventually into the individual minerals of which they are composed. As a result of weathering the rock fragments and the minerals are changed to new minerals either by alteration or by complete chemical changes.

Weathering processes are distinguised into the following three types on the basis of nature of agencies which bring about weathering :

(1) Physical weathering,

(2) Chemical weathering,

(3) Biological weathering or Biogeochemical weathering.

(1) Physical Weathering

Physical weathering of rocks is a mechanical process which is brought about by a number of factors, such as :

(A) Temperature,

(B) Water,

(C) Wind.

(A) Temperature. It causes breakdown of rocks in the following ways :

(i) Differential Expansion and contraction of materials. Minerals composing the rock have got different degrees of expansion (coefficient of expansion). These minerals expand in the light temperature of day and contract when the temperature falls. The differential expansion and contraction of different minerals set up internal tension and produce cracks in the rocks and thus the rocks weather into finer and finer particles.

(ii) Exfoliation. The arrangement of layers in rock is called expliation. Layer differentiation is not common in all types of rocks. The upper layer of rocks expand and contract faster than those of deeper region. The temperature changes bring about separation and disintegration of the surface layers of rocks. This process is known as exfoliation.

(iii) Frost Action. Sometimes, temperature of rocks reaches below freezing point. This causes accumulation and freezing of water in the crevices and rock joints. In freezing, water expands to about 9 per cent of its original volume and exerts a pressure of approximately 150 tons per square feet which is more than enough to break the rocks.

(B) Water. Water causes weathering of rocks in the following ways :

(i) Rain. Natural water falling either in the form of rain drops or as hail storm on the surface of rocks with beating effect bring about abrasion of massive rocks into smaller particles.

(iii) Running Water. Rapidly flowing water rolls the heavy rock masses (rock boulders) along the bottom of stream and grinds them into finer particles.

(iii) Wave Action. It is most active in sea shores. The water waves when strike with great force on the rock surface break and grind the rock into pieces.

(iv) Glacier Formation. At mountain tops, ice formation takes place in the winter season. When the summer approaches, ice starts melting and glaciers (huge sliding masses of ice) move downwardly on the slopes. In the glacier movement, the rocks are corroded and finally broken into sand particles (Fig. 16.1

(C) Wind. Rapid stormy wind carrying suspended sand particles causes the abrasion of exposed rock. The figure 16.2 shows rocks which were subjected to wind erosion.

(2) Chemical Weathering

Chemical weathering brings about disappearance of original rock minerals either completely or partly. In this process secondary products may be formed from parent materials. This process is also known as chemical transformation. Presence of moisture and air is very essential in the chemical weathering. This is why chemical weathering is not so effective in desert.

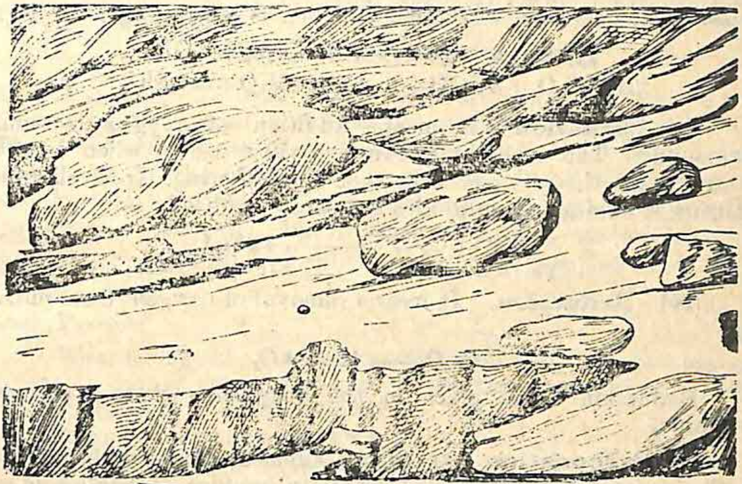


Fig. 16·1—Moving glaciers cause cutting and crushing of the bed rocks.

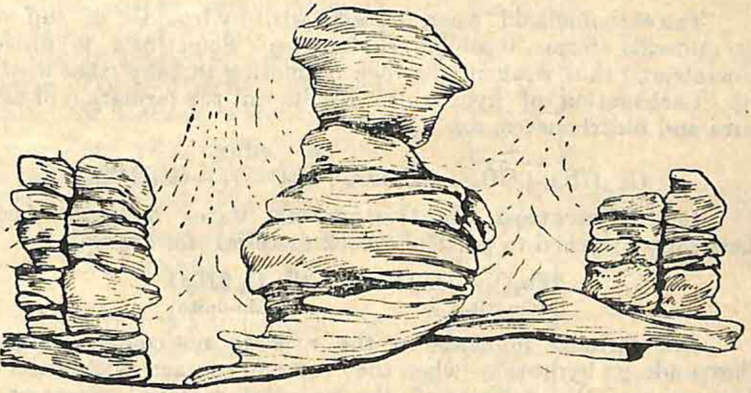


Fig. 16·2 —Effect of wind on the rocks.

The chemical weathering takes place in the following ways :

(i) Solution. Solvent action of water helps in the weathering of rocks. It dissolves soluble minerals of rocks. Solution helps in the removal of weathered materials but total loss is negligible. Solvent action is increased in presence of CO_2 and organic acids formed by decomposing dead organic remains of plants and animals.

Sodium, potassium, calcium and magnesium are easily removed from rocks in dissolved state.

(ii) **Hydrolysis**. It is essentially an exchange of constituent parts between water and rock minerals. When water unites with strong base it produces hydroxides. The soluble products of hydrolysis are usually removed by water. Sometimes soluble products may react with insoluble ones and form clays. Hydroxides in presence of CO_2 change to carbonates and bicarbonates. Water in ionised state acts as a weak acid on silicious matter, *e.g.*,

$$KAlSi_3O_8 + HOH \longrightarrow HAlSi_3O_8 + KOH.$$

$$2HAlSi_3O_8 + 8HOH \longrightarrow Al_2O_3\ 3H_2O + 6H_2SiO_3\ .$$

(iii) **Oxidation**. It means addition of oxygen to mineral compounds. The reaction produces oxides which when dissolve in water weaken the rock and bring about weathering. Iron, aluminium, manganese oxides and sulphides are easily oxidised.

$$\underset{\text{(Ferrous oxide)}}{4FeO + O_2} \longrightarrow \underset{\text{(Ferric oxide)}}{2Fe_2O_3}$$

(iv) **Reduction**. It means removal of oxygen from minerals, *e.g.*,

$$2Fe_2O_3 \longrightarrow 4FeO + O_2$$

Reduction takes place in the deep zone where oxygen is not available.

(v) **Carbonation**. It occurs simultaneously with hydrolysis. In this process, CO_2 unites with water to produce carbonic acid which is a weak acid.

$$CO_2 + H_2O \longrightarrow H_2CO_3 \text{ (Carbonic acid)}$$

The carbonic acid, when it reacts with hydroxides of soil forming minerals, forms insoluble carbonates. Sometimes it dissolves minerals and thus weakens the rock promoting thereby the weathering. Carbonation of hydroxides results in the formation of carbonates and bicarbonates, *e.g.*

$$Ca\ (OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O \xrightarrow{+CO_2} Ca(HCO_3)_2$$

(vi) **Hydration**. In this process, water molecules become chemically attached to particular rock material, for example :

$$\underset{\text{(Hematite)}}{2Fe_2O_3 + 3H_2O} \longrightarrow \underset{\text{(Limonite)}}{2Fe_2O_3.3H_2O.}$$

Soil forming minerals in the rock do not contain any water. They undergo hydration when they come in contact with water. In this process, the volume of the parental material increases and hydrated materials become soft and more readily weatherable.

(3) Biological Weathering

Many organisms play important roles in the weathering of rocks through physical and chemical means. Important organisms concerned with the decomposition of rocks are lichens, bacteria, fungi, higher plants, nematodes and other soil microbes. Lichens and some other organisms in presence of moisture secrete carbonic acid which corrodes the rock.

The presence of roots on the surface of rock exerts a considerable pressure by which rocks are broken into smaller fragments. The root exudates also weaken the rocks and weather them to a small extent.

Joffe (1949) states that there is no biogeo-chemical weathering. According to him, it is either physical or chemical weathering by biological agencies.

SOIL FORMING PROCESS

The surface rocks of the earth are weathered and as a result of weathering, small particles of parental materials are formed. The weathering process continues until all the essential elements locked up in the rocks become available to all sorts of organisms. Simultaneously with weathering process, pedogenesis or soil forming process also runs which leads weathered materials to develop into mature soil with well differentiated soil profiles and biological system.

Soil Profile

Weathering of parental rocks results in the development of several loose layers or horizons of weathered materials. Biological system, addition of organic matter (humus) and interaction between organic and mineral compounds make the horizons more distinct. The complete succession of horizons down to the level of undifferentiated parent materials is called *solid profile*. In other words, it is vertical section of earth crust showing different layers or horizons of soil.

The soil profile may be divided into the following three zones or horizons (Fig. **16·3**) :

(1) A horizon (top soil or zone of extraction),

(2) B horizon (subsoil or subsurface zone), and

(3) C horizon (Regolith).

Some workers have recognised D horizon below C Horizon.

(1) A Horizon. It is the top soil which consists of mineral matter and organic residues. The soluble chemicals are leached away by water.

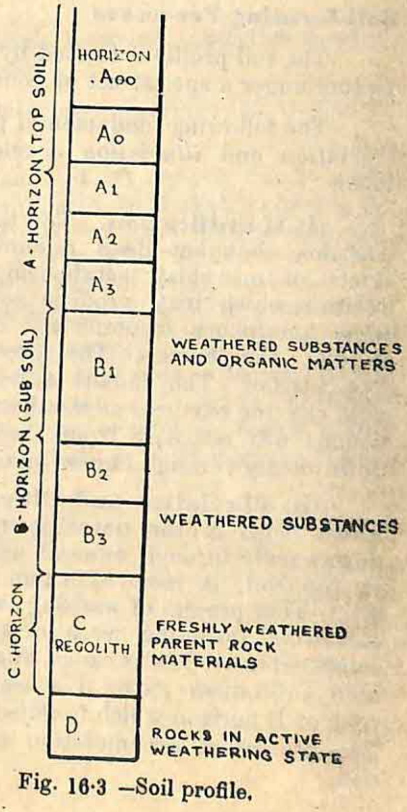

A-HORIZON (TOP SOIL)
B-HORIZON (SUB SOIL)
C-HORIZON
HORIZON Aoo
Ao
A1
A2
A3
B1
B2
B3
C
REGOLITH
D
WEATHERED SUBSTANCES AND ORGANIC MATTERS
WEATHERED SUBSTANCES
FRESHLY WEATHERED PARENT ROCK MATERIALS
ROCKS IN ACTIVE WEATHERING STATE

Fig. 16·3 —Soil profile.

Upper horizon (A) is very loose and it supports vegetation Because it is full of organic elements and minerals, the top soil is. very fertile. The thickness of A horizon varies from one to ten feet. A horizon is differentiated into several sub-layers which are Aoo, Ao. A_1, A_2, A_3. These can be distinguished by their distinct colours and textures.

(2) **B Horizon**. A zone of soil present below the top soil or A horizon is called B horizon. It is also known as sub-soil. In this zone, the weathered substances or minerals are deposited and organic residues are present in very small quantities This horizon is *lighter in colour* than A horizon. B horizon can also be differentiated in several subzones, as B_1, B_2, B_3 and so on, on the basis of colour and texture. Upper subzone of B horizon, which is just below the top soil (A horizon), is looser than lower subzones.

(3) **C Horizon (Regolith)**. Below B horizon and above the surface of weathered rock, there is a third horizon, the *C horizon* or zone of regolith. It is formed of freshly weathered parental materials.

Below the C horizon, there may be found rock in active weathering state. This is recognised as a fourth zone or **D horizon** by some workers.

Soil-forming Processes

The soil profile is formed by interaction of various pedogenic factors under a special set of conditions.

The following fundamental processess namely *humification* and *eluviation* and *illuviation* develop a profile. These are described below :

(i) **Humification**. Top layer of the soil, called A horizon, contains abundant dead remains of plants, animals and other products of microbial metabolism. These products undergo decomposition which may produce some soluble organic compounds and some amorphous incompletely decomposed black coloured organic residue, the *humus*. The process of humus formation is called *humification*. The humus and organic compounds become mixed with the fine particles of weathered rock. Some soluble organic compounds are removed from the top soil by water which percolates downwardly through humus mixed soil.

(ii) **Eluviation and illuviation**. Water is important agent which helps in the development of soil profile. While percolating downwardly through mineral and organic substances of A horizon or top soil, it removes a number of soluble chemicals from the top soil. This process of washing away of soil constituents is termed as *eluviation* (meaning wash out) and the surface layer from which components are lost is called *eluvial layer* or A horizon. The eluviated substances move downwardly and are deposited in the lower zone or B horizon which is called *illuvial layer* (meaning 'wash in'). The process of accumulation of eluviated materials is called *illuviation*.

The fundamental soil-forming processes involved in the development of soil profile are described below :

(i) **Gleization**. This process takes place in wet and cold Tundra regions where saline conditions do not exist. In this process, there develops a compact structureless and sticky surface layer. This layer is blue green in colour, poorly aerated and has reduced content of iron compounds. It favours surface accumulation of peat materials and undergoes a series of chemical, physical and biological changes which produce a characteristic soil.

(ii) **Podzolisation**. In temperate zones where climate is cold and moist, the rate of decomposition is slow and in the decomposition process acids are produced which make the soil acidic. The acidic unproductive soil is called 'podzol' and the process is called 'podzolisation'. In the process of podzolisation humus and some minerals including dissolved Si, Fe and Al salts from A horizon move downwardly with percolating water and accumulate in the lower horizons. This process is more effective in sandy base-poor parent materials under intense leaching and thick vegetational cover.

(iii) **Laterisation**. In tropical and subtropical regions, when rainfall occurs the organic matter and minerals are leached away and hydroxides of aluminium and iron are precipitated in the form of residue which is called 'laterite'. This process is termed as *laterisation*.

In this process, silica is completely removed. Laterites usually do not show well differentiated horizons.

Podzol and laterites are collectively described as 'pedalfer group' (iron accumulating group).

(iv) **Calcification**. In subhumid and dry regions, due to lack of excessive moisture the soil accumulates considerable amount of soluble materials and **carbonates** of calcium and magnesium are deposited in B horizon. The soil having such features is called *pedocal* (calcium accumulating soil). Soils are not acidic and calcium content in them is very high. This process is common in grasslands.

Hydromorphic Profile Development. Such soil-forming processes result in swamp, bog, marsh and peat soils and occur under conditions when percolation is restricted and certain horizons become saturated with water. These two conditions result in the development of anaerobic conditions, as well as beginning of more chemical reduction processes.

Factors Affecting Soil Formation

These are outlined as under :

(1) Climate,
(2) Biosphere,
(3) Parent material,
(4) Relief,
(5) Time.

All these factors are interrelated and complementary to one another. Some of them may be more influential under a particular set of conditions in determining the nature of soil while the other may be less influencing. Any soil property is a collective function or the effects of all pedogenic factors.

Joffe (1949) creates the following two categories in the soil forming factors :

(i) **Active Factors.** These include agents which supply energy for soil formation. Climate and biosphere are the two important active factors.

(ii) **Passive Factors.** These include the sources of soil forming mass and the conditions affecting it. Parent material, relief and time are the three passive factors.

1. **Climate.** It shows the following effects on pedogenesis :

(*i*) Heavy rainfall and high relative humidity favour the soil formation or pedogenesis. Low rainfall and low relative humidity show retarding effects on the process.

(*ii*) Severe erosion of materials by wind also affects the process adversely.

(*iii*) Horizons tend to develop faster under cool and humid forest conditions.

2. **Biological Factors influencing the Pedogenesis.** Biological agents affect the soil formation in a number of ways :

(*i*) Large number of burrowing animals upturn the deep soils and thus disturb the soil profile development.

(*ii*) Man's activities, such as manuring, ploughing, drainage, irrigation, cropping system, reclamation also affect the pedogenesis to a great extent.

(*iii*) Addition of organic residues and mixing them with minerals promote the differentiation of soil profile.

(*iv*) Vegetation exerts its main influence on pedogenesis through the amount and nature of organic matter which it adds to the soil and by checking the soil erosion.

3. **Nature of Soil Forming Parental material mass.** This affects pedogenesis in the following ways :

(*i*) High percentage of clay in the weathered materials has retarding effect on pedogenesis.

(*ii*) Resistant parental materials, such as granite if present in parent material mass, do not promote the soil formation.

(*iii*) Excessive sandyness of parent materials reduces the rate of soil formation.

(*iv*) Materials with low silt and clay percentages do not differentiate into soil profile quickly.

(*v*) Heavy accumulation of soil materials also has retarding effects.

(*vi*) High lime content in the parent material checks profile differentiation.

Time. Length of time required for soil formation depends upon many interrelated factors, such as climate, biosphere, nature of parent materials etc.

Relief. Some of the important effects of relief in the pedogenesis are as follows :

Topography determines the drainage condition and ground water level in the soil. High water table shows influence in the horizon differentiation. Very steep slopes do not promote pedogenesis because of the fact that deposition of parent materials is affected by downward flowing water. If anyhow soil is formed, water content in such a soil is very poor.

Soil materials on moderate slopes promote deeper profile development and more luxuriant vegetation than in soil on steep slopes.

In soil survey Manual of U.S. Department of Agriculture (USDA) the interrelationship of pedogenic factors has been concluded as follows :

"Soil characteristics in any one place result from the combined influence of climate and living matter, upon the parent rock materials, as conditioned by relief (topography), over periods of time including the effects of the cultural environment and man's use of soil."

QUESTIONS

1. What are different minerals composing the rocks ? Give an account of different weathering processes which bring about breakdown of mineral rocks.
2. Give an account of soil forming process and discuss the effects of various factors in pedogenesis.
3. Write short notes on :
    - (*i*) Humification.
    - (*ii*) Eluviation and illuviation.
    - (*iii*) Soil profile.

17

PROPERTIES OF SOILS

A. PHYSICAL PROPERTIES OF SOILS

Physical properties of the soil can be discussed under the following heads :

1. (1) Soil separates and texture,
2. (2) Structure of soil,
3. (3) Weight and soil density,
4. (4) Porosity of soil,
5. (5) Permeability of soil,
6. (6) Soil colour,
7. (7) Temperature of soil,
8. (8) Soil Plasticity, Cohesion and Adhesion.

(1) Soil Separates and Soil Textures

Mineral fraction of soil consists of particles of various sizes. According to their size, soil particles grouped into the following types :

Names of soil particles	*Diameter range of soil particles in millimetre*
1. Coarse particles or gravels	More than 2·00
2. Coarse sands	2·00—0·20
3. Fine sands	0·20—0·02
4. Silts	0·02—0·002
5. Clays	Below 0·002

The particle sizes of above groups are suggested by International Society of Soil Science. In India; international system of particle differentiation is commonly followed. The particle types are generally called 'soil Separates' or 'soil fractions'.

Amount of soil separates is determined by a process known as mechanical analysis. In this process, soil sample is crushed and screened through a 2 mm round hole sieve. The screened soil is then homogeneously dispersed in water and allowed to settle.

In suspension, particles of largest dimensions will settle first and those with smaller dimensions will settle afterwards. Individual soil separates are identified on the basis of their respective diameter ranges.

Soil separates (sand, silt and clay) differ not only in their sizes but also in their bearing on some of the important factors affecting plant growth, such as, soil aeration, workability, movement and availability of water, and nutrients. Important characteristics of different soil separates are as follows :

Sand. This fraction of soil consists of loose and friable particles of 2·203—·02 mm diameter. Sand particles can be seen with unaided eye. These particles, although inactive, constitute the framework of the soil. They play little important role in physicochemical activities. When coated with clay, these sand particles take very active part in chemical reactions. Sands increase the size of pore spaces between soil particles and thus, facilitate the movement of air and water in the soil.

Silt. It consists of soil particles of intermediate sizes between sand and clay (diam. range : ·02—·002 mm). Silt when wet feels plastic but in dry state feels like flour or talcum. Coarse silt shows little physicochemical activities but finer grades play important role in some chemical processes. Silty soil has got larger exposed surface area than the sandy soil. Silty soil contains sufficient quantities of nutrients, both organic and inorganic. That is why they are very fertile. Soils rich in silt possess great water holding capacity. Such soils are good for agriculture.

Clay. This soil fraction contains smallest particles (below ·002 mm diameter) which exhibit plasticity and smoothness when wet and hard when dry. Owing to their smallest size and colloidal nature, the clay particles expose extremely large surface area. They take very active part in physicochemical reactions of the soil. Clay soils have fine pores, poor drainage and aeration and thus they have highest water holding capacity. The clay acts as store house for water and nutrients.

Some soils are fine, while others are coarse. It is so because of the fact that the relative percentages of sand, silt and clay differ from soil to soil. The relative percentage of soil separates in a given soil is referred to as soil texture. Texture of soil for a given horizon is almost a permanent character, because it remains unchanged over a long period of time. The relative percentages of soil separates of average samples are almost infinite in possible combinations. It is, therefore, necessary to establish limits of variations among soil fractions so as to group them into textural classes. The common texture classes, as recognised by USDA (U.S. Department of Agriculture) are given in the following table. These classes are recognised on the basis of relative percentage of separates, sand, silt and clay.

Soil classes or textural names	*Range in relative percentage of soil separates*		
	Sand	*Silt*	*Clay*
Sandy soil	85—100	0—15	0—10
Loamy sand	70—90	0—30	0—15
Sandy loam	43—80	0—50	0—20
Loam	23—52	28—50	7—27
Silt loam	0—50	50—88	0—27
Silt	0—20	8—10	0—12
Sandy clay loam	45—80	0—28	20—35
Clay loam	20—45	15—53	27—40
Silty clay loam	0—20	40—73	27—40
Sandy clay	45—65	0—20	35—45
Silty clay	0—20	40—60	40—60
Clay	0—45	0—40	40—100

This chart is adapted from fraction system of U.S.D.A.

If relative percentages of soil separates are known, the soil can be given textural name. For this purpose equilateral triangles are used. The most widely used international equilateral triangle is shown in Fig. 17·1. This consists of three angles and its area is divided into twelve groups representing twelve different textural classes. Each group covers definite range of percentages of sand, silt, and clay. In the triangle, left side line represents the clay %, right side line represents percentage of silt and base represents percentage of sand. Each arm of the triangle is divided into ten divisions representing soil separate's percentage. These divisions are further divided into ten small divisions; each small division represents one per cent of soil separate. The percentages of sand, silt, and clay obtained after mechanical analysis of the given soil are read on the equilateral triangle. In using the diagram as indicated the percentages of silt and clay should be located on silt and clay lines respectively. The line in case of silt is then projected inward parallel to clay side of the triangle and in case of clay it should be projected parallel to the sand side. The three lines one representing sand percentage, other representing silt percentage and the third clay percentage, meet at a point in the triangle. The compartment in which the point falls indicates textural name for the given soil sample.

The knowledge of soil texture is of great help in the classification of soil and in determination of degree of weathering of rock.

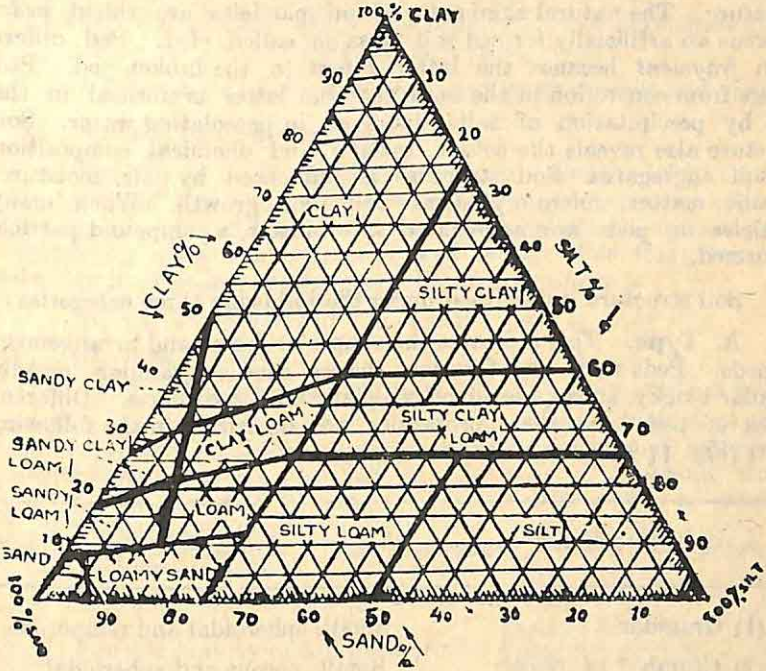


Fig- 17·1 —International equilateral triangle for textural classification of the soil·

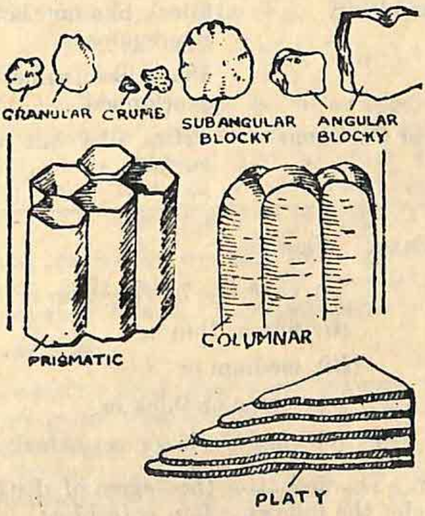


Fig. 17·2 Soil Structure.

2. Structure of Soil

Sand, silt and clay are found in aggregated form. Arrangement of these soil particles on certain defined patterns is called soil structure. The natural aggregates of soil particles are called *peds*, whereas an artificially formed soil mass is called *clod*. Ped differs from *fragment* because the latter refers to the broken ped. Ped differs from concretion in the sense that the latter is formed in the soil by precipitation of salts dissolved in percolating water. Soil structure also reveals the colour, texture and chemical composition of soil aggregates. Soil structure is influenced by air, moisture, organic matter, micro-organisms and root growth. When many particles or peds are aggregated into cluster, a compound particle is formed.

Soil structure is described under the following three categories :

A. Type. This indicates the shapes or forms and arrangement of peds. Peds may be of various shapes, such as granular, crumb, angular blocky, subangular blocky, platy and prismatic. Different types of peds and their properties are described in the following chart (Fig. 17·2).

Types of ped	*Properties*
(1) Granular	Small, spheroidal and nonporous.
(2) Crumb	Small, porous and spheroidal.
(3) Angular blocky	Block like with sharp ends, one end may be pointed.
(4) Subangular blocky	Block like but bounded by other aggregates.
(5) Platy	Plate like, sometimes plates are overlapped.
(6) Prismatic or Columnar	Prism like but without rounded surface.

B. Size Class. Whether

(*i*) very fine or very thin or

(*ii*) fine or thin or

(*iii*) medium or

(*iv*) coarse or thick or

(*v*) very coarse or very thick

C. Grade. This indicates the degree of distinctness of peds. It is described under the following four categories :

(*i*) **Structureless** :—Peds not distinct, *i.e.*, cement or sand-like condition.

(*ii*) **Weak** :—Peds distinct and barely durable.

(*iii*) **Moderate** :—Peds moderately well developed, fairly durable and distinct.

(*iv*) **Strong** :—Peds well developed, quite durable and distinct.

3. Density and Soil Weight

Density of soil is the mass per unit volume. It is expressed in terms of gm per cubic centimeter. Average density of the soil is 2.65 gms per cubic centimeter. Density of soil varies greatly depending upon the degree of weathering. For this reason soil density is expressed in two generally accepted forms :

(*i*) particle density or true density ; and

(*ii*) bulk density.

(*i*) **Particle density**. Density of solid portion of soil is called particle density. It is sum total of densities of individual organic and inorganic particles. Average particle density of organic soil varies from 1·2 to 1·7 gms per cc and that of inorganic fraction varies from 2·6 to 2·78 gms cc. Particle density may be calculated as : $\frac{\text{weight of solids}}{\text{volume of soils}}$. Particle density divided by density of water gives the specific gravity or relative weight number.

$$\text{Specific gravity of soil particles} = \frac{\text{particle density}}{\text{density of water}}$$

(*ii*) **Bulk Density or Apparent density**. Dry weight of unit volume of soil inclusive of pore spaces is called bulk density. It is expressed in terms of gm per cc or lbs per cubic foot. It is lesser than the particle density of the soil. Bulk density of soil may be calculated as : $\frac{\text{weight of soil}}{\text{volume of soil}}$. Bulk density of the soil divided by density of water gives volume weight or apparent specific gravity of soil. Bulk density of soil changes with the change in total pore space present in the soil and it gives a good estimate of the porosity of soil. Average density of soil in bulk is 1·5 gm cc. Organic soils have low bulk density as compared to mineral soils.

Soil weight varies in relation to textural classes. Average weight of loam or sandy soil is 80—110 pounds/cubic foot but that of clay ranges between 70 and 100 pounds/cubic foot.

(4) Porosity of Soil

The spaces occupied by air and water between particles in a given volume of soil are called pore spaces. The percentage of soil volume occupied by pore space or by the interstitial spaces is called porosity of the soil. It depends upon the texture and structure, compactness and organic content of the soil. Porosity of the soil increases with the increase in the percentage of organic matter in the soil. Porosity of soil also decreases as the soil particles become much smaller in their dimension because of decrease in pore spaces. It also decreases with depth in the soil. The pore spaces are responsible for better plant growth because they contain enough air moisture. Percentage of solids in soils can be determined by comparing bulk density and particle density and multiplying by hundred.

$$\text{percentage of solids} = \frac{\text{Bulk density}}{\text{particle density}} \times 100$$

This percentage of solids subtracted from total volume (100%) will give the percentage of pore space. Hence, the formula :

$$100\% - \left(\frac{\text{bulk density}}{\text{particle density}} \times 100 \right) = \text{percentage of pore space.}$$

Depending upon the size of pores, pore spaces fall into two categories. These are :

(1) **Micropore** spaces (capillary pore spaces)

(2) Macropore spaces (non-capillary pore spaces)

Capillary pore spaces can hold more water and restrict the free movement of water and air in soil to a considerable extent, whereas macropore spaces have little water holding capacity and allow free movement of moisture and air in the soil under normal conditions.

(5) Permeability of Soil

The characteristic of soil that determines the movement of water through pore spaces is referred to as soil permeability.

Soil permeability, because it is directly dependent on the pore size, will be higher for the soil with large number of macropore spaces than that for compact soil with a large number of micropore spaces (capillary spaces). Permeability of soil also varies with moisture status and usually decreases with the gradual desiccation of soil. In the arid regions, ground water moves upwardly through capillary action and brings sodium, potassium and calcium salts with it in dissolved state on the surface of soil. The water evaporates and inorganic salts precipitate on the surface of the soil. As a result of this, the soil becomes less permeable and the productive capacity of soil is reduced.

(6) Soil Colour

Soils exhibit a variety of colours. Soil colour may be inherited from the parental material (*i.e., lithochromic*) or sometimes it may be due to soil forming processes (*acquired* or *genetic colour*). The variations in the soil colour are due to organic substances, iron compounds, silica, lime and other inorganic compounds.

The organic substances impart black or dark greyish black colour to the soils. Iron compounds are responsible for brown, red and yellow colours of soils. Iron oxides in combination with organic substances impart brown colour which is most common soil colour. Silica, lime and some other inorganic compounds give light white and grey tinges to the soil.

Soil colour influences greatly the soil temperarure. The dark coloured soils absorb heat more readily than light coloured soils. The work of Ramdas, L. A. and David, R. K. (1936) at Poona showed that black cotton soil absorbed 86% of the total solar radiations falling on the soil surface as against 40% by the grey alluvial soil. Soil colour is used as an important criterion for description and classification of soil. Many soils are named after their prominent colours such as black cotton soil, red-yellow Latosol, grey hydromorphic soils and so on.

(7) Soil Temperature

The chief sources of soil heat are solar radiations and heat generated in the decomposition of dead organic matters in the soil and heat formed in the interior of earth. The soil temperature greatly affects the physico-chemical and biological processes in the soil. Temperature of soil depends upon the temperature of atmospheric air and on moisture content. It is controlled by climate, colour of soil, slope, and altitude of the land and also by vegetational cover of the soil. The average annual temperature of soil is generally higher than that of its surrounding atmosphere. Ramdas and M. S. Katti (1934) recorded surface temperature of black cotton soil as high as 165°F at Poona (Maharashtra), India. Surface temperature of soil shows considerable fluctuations but soil temperature below certain depth remains more or less constant and is not affected by diurnal or seasonal temperature changes.

Studies made by Leather at Pusa Research Institute in Bihar (India) showed that diurnal temperature difference at the level 12 inches below the soil surface was only 1°C and at a depth of 24″ it seldom exceeded 0·1°C. At the depth of 3 or 4 feet, the temperature remains almost constant.

(8) Soil Plasticity, Cohesion and Adhesion

Soil plasticity is a property that enables the moist soil to change shape when some force is applied over it, and to retain this shape even after the removal of that force from it. The plasticity of soil depends on the cohesion and adhesion of soil materials. Cohesion refers to the attraction of substances of like characteristics such as that of one water molecule for another. Adhesion refers to the attraction of substances of unlike characteristics. Soil consistency depends on the texture and amount of inorganic and organic colloids, structure and moisture contents of soil. With the decrease in the moisture contents soils gradually tend to become less sticky and less plastic and finally they become hard and coherent. Plastic soils have great cohesion force It is only because of cohesion property the moist clay soils frequently develop cracks when they become dry (Fig. 17·3).

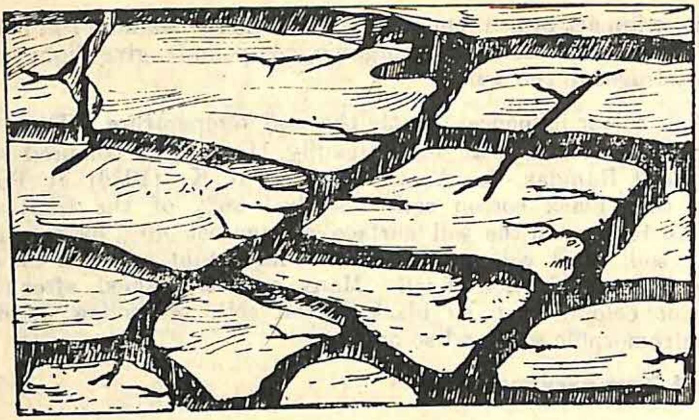


Fig. 17·3 Diagram showing soil cracking due to shrinkage.

B. CHEMICAL PROPERTIES OF SOILS

Chemical properties of soils can be described under the following heads :

(1) Inorganic matters of soil ;

(2) Organic matters in soil ;

(3) Colloidal properties of soil particles ;

(4) Soil reactions and Buffering action ;

  (*i*) Acidic soils ;

  (*ii*) Basic soils.

(1) Inorganic Matters of Soil

From the accounts given in the description of weathering process it is clear that compounds of aluminium, silicon, calcium, magnesium, iron, potassium and sodium are chief inorganic constituents of soils. Besides these, the soils also contain small quantities of several other inorganic compounds, such as those of boron, magnesium, copper, zinc, molybdenum, cobalt, iodine, fluorine etc. The amounts of these chemicals vary in soils of different places. Chemical composition of soil of one horizon differs greatly from the composition of soil in the other horizon.

(2) Organic Matters in Soil

Organic component of the soil consists of substances of organic origin ; living and dead. In sandy soil of arid zone, it is found in very poor quantity (one or less than one per cent) but in peaty soil, it may be as high as 90%. When the plants and animals die, their dead remains are subjected to decomposition. As a result of decomposition a number of different organic products or compounds are formed from the original residues. In the course of decomposition, the original materials are converted into dark coloured organic complexes, called *humus*. Sometimes living microorganisms add sufficient amount of organic matters in soil in the form of metabolic wastes. Chemists have been attempting to unravel the details of humus composition since the earliest days of soil science, and have got much success but much is still to be discovered. In terms of specific elements, the organic component of soil contains compounds of carbon, hydrogen, oxygen, phosphorus, nitrogen, sulphur and small amount of other elements also. Only small fraction of total organic matter is soluble in water but majority of them are soluble in alkali solution. Chemically humus contains the following organic molecules :

A. Amino Acids

- (*i*) Glutamic acid
- (*ii*) Alanine
- (*iii*) Valine
- (*iv*) Proline
- (*v*) Cystine
- (*vi*) Phenyl alanine

B. Proteins

- (*I*) *Purines*
  - (*i*) Guanine
  - (*ii*) Adenine
- (*II*) *Pyramidines*
  - (*i*) Cytosine
  - (*ii*) Thymine
  - (*iii*) Uracil

C. Aromatic molecules

D. Uronic acids

- (*i*) Glucuronic acid
- (*ii*) Galacturonic acid
- (*iii*) Lactic acid

E. Aliphatic acids

- (*i*) Acetic acid
- (*ii*) Formic acid
- (*iii*) Succinic acid

F. Aminosugars

- (*i*) Glucosamine
- (*ii*) N. Acetylglucosamine

G. Pentose sugars

- (*i*) Xylose
- (*ii*) Arabinose
- (*iii*) Ribose

H. Hexose sugars

- (*i*) Glucose
- (*ii*) Galactose
- (*iii*) Manose

I. Sugar alcohols

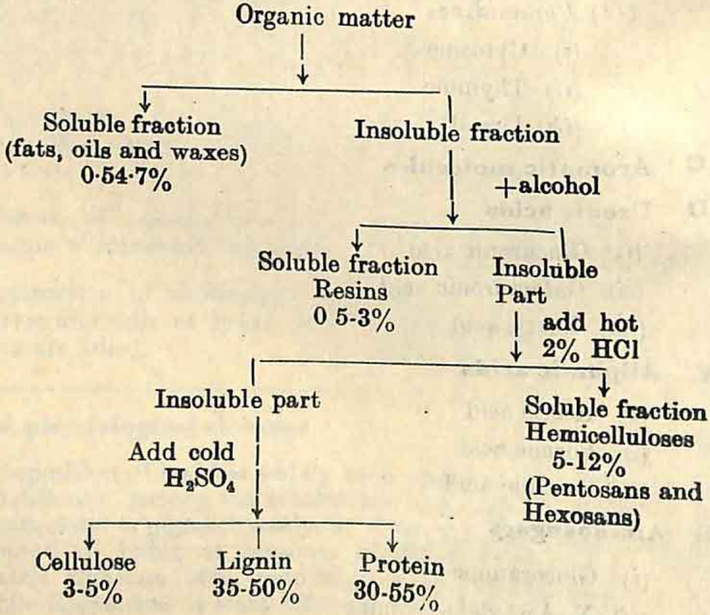
- (*i*) Inosital
- (*ii*) Mannitol

J. Methyl sugars

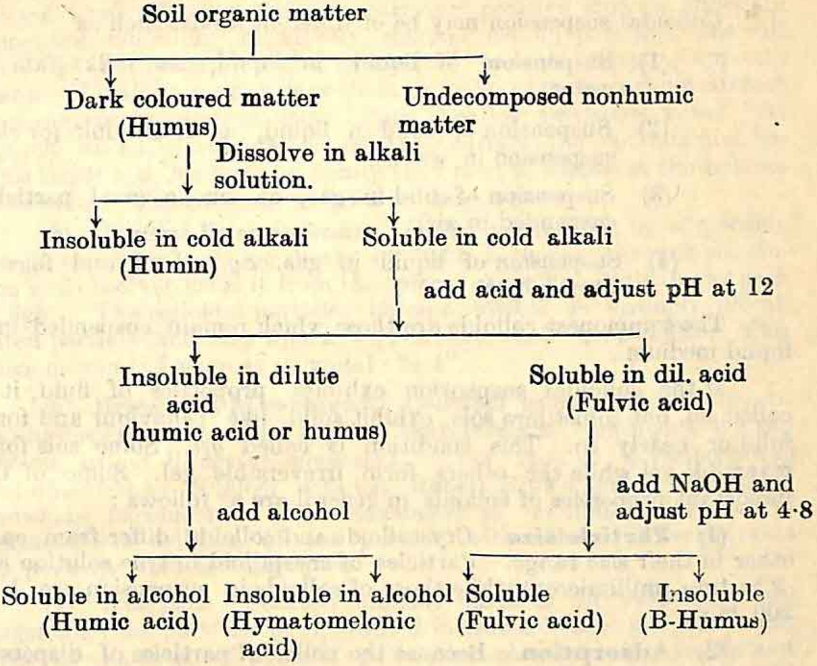
- (*i*) Rhamnose
- (*ii*) Fucose
- (*iii*) 2-O, methyl D-xylose
- (*iv*) 2-O, methyl D-arabinose

Besides these compounds locked up in the humus fraction, the soil also contains fats, oils, waxes, resins, tannin, lignin and some pigments.

Waksman and Stevans have proposed the following method for separation of different organic compounds present in the soil :



Another modified method for separation of the various organic compounds from the soil is as follows :



The fractions are not pure chemical compounds but are in the form of mixtures of several substances. They are found in colloidal state in the soil.

3. Colloidal Properties of Soil Particles

There are two types of substances, namely crystalloids and colloids.

Crystalloids are those crystalline solid substances which form true solution on being mixed with other substances. In true solution, crystal particles cannot be seen with the help of microscope.

The word colloid first coined by Grahm (1849) is derived from Greek words *kolla* meaning glue and *eoids* meaning appearance, *i.e.*, glue like in appearance. Colloid is really speaking amorphous state of the substances which do not form true solution if mixed with other substances. The particles of colloidal substances float in the solvent in suspension state but do not tend to settle at the bottom. Colloids are not found in ionic or molecular form but are found in aggregates of atoms or molecules. Colloidal system or suspension contains two phases which are –

(*i*) Dispersion phase, *i. e.*, medium in which the particles are suspended, (*ii*) Dispersed phase, *i. e.*, suspended particles.

Colloidal suspension may be of different kinds, such as

(1) Suspension of liquid in liquid, as milk (fats in water).

(2) Suspension of solid in liquid, as India ink (or clay suspension in water).

(3) Suspension of solid in gas, as smoke (coal particles suspended in air).

(4) Suspension of liquid in gas, *e.g.*, cloud and fogs in atmosphere.

The commonest colloids are those which remain suspended in a liquid medium.

If the colloidal suspension exhibits properties of fluid, it is called *sol*, but sometimes sols exhibit solid like behaviour and form solid or nearly so. This condition is called *gel*. Some sols form reversible gel while the others form irreversible gel. Some of the important properties of colloids in general are as follows :

(1) **Particle size.** Crystalloids and colloids differ from each other in their size range. Particles of crystalloid in true solution are ·2 to 1mμ (millimicron) while those of colloids in suspension are 1 to 200 mμ.

(2) **Adsorption.** Because the colloidal particles of dispersed phase are very small, they have got large exposed surface areas. Owing to their large exposed surface areas, these colloidal particles show great adsorptive capacity. In adsorption, particles of particular substances come to lie on the surface of colloids and they do not enter deep in the colloidal particles.

(3) **Electrical Properties.** The electrically charged colloids are termed as *micelles*. Colloids have some electrical charge on them. They may be charged either positively or negatively. Colloidal particles of one electrical charge have tendency to attact colloids of opposite charge. In the soil, clay particles are negatively charged, thus they attract cations (+charged ions).

Colloid particles differ from electrolytes in the fact that when electric current is passed in the colloidal suspension, all the colloidal particles are attracted towards one electrode or the other depending upon the nature of charge they carry on them. This phenomenon is called as *electrophoresis*. The electrolytes, when dissolved in solvent, dissociate into two types of ions among which half will bear positive charge (**cations**) and remaining half will bear negative charge (anions). When electric current is passed in the solution of electrolyte all the positively charged ions will accumulate on negative pole and remaining negatively charged ions will collect on positive pole.

(4) **Coagulation or Flocculation of Colloidal particles.** Colloidal particles in the suspension can be coagulated either by

heating or by adding some substances which contain oppositely charged ions. When substances carrying positive ions are added in suspension containing negatively charged colloid particles, ions will move and accumulate on the surface of colloids carrying opposite charge. Finally a stage comes when calloidal particles cannot attract more oppositely charged ions. This is called *isoelectric point*. As a result of ion accumulation on their surface, the colloids first become larger and heavier and finally they tend to settle at the bottom in floccules. This process is known as *flocculation*.

(5) **Tyndal Phenomenon**. Colloidal particles in suspension can be seen when a strong beam of light is passed through suspension and observer looks it from the place at right angle to the path of light. The colloidal particles become visible as strongly illuminated particles and they appear bigger than their normal size. This phenomenon is known as "Tyndal effect".

(6) **Brownian Movement**. Colloidal particles when suspended in dispersion medium show a characteristic continuous zig-zag motion, called *Brownian movement*. This type of movement was first observed by English botanist Robert Brown, hence it is called Brownian movement. The movement is exhibited because of characteristic collision of one particle with others. This prevents the particles from settling down.

(7) **Dialysis**. Because colloidal particles in suspension are larger than the particles of crystalloid in true solution and are larger than the diameter of pores of porous membranes, *e.g.*, parchment membrane, they are not allowed to be filtered down and are retained by the membrane. Thus, they can be separated in pure state from the mixture of crystalloids and colloids by filtration process. This separation process is known as *dialysis*.

Colloidal fraction of soil

There are two types of colloids in the soil. These are :

(1) mineral colloids or clay colloids, and

(2) organic or humus colloids.

These two colloidal fractions of soil are very intimate to each other and it is very difficult to separate them. The inorganic colloids occur as very fine particles and organic colloids occur in the form of humus particles. The soil colloid particles show almost all the characteristics of typical colloidal system, *i.e.*, adsorption, Tyndal effect, Brownian movement, coagulation, electrophoresis, dialysis etc.

(1) **Clay Colloids**. As regards the size, clay fraction of soil contains both non-colloidal and colloidal particles. Some clay particles may be as large as ·002 mm in diameter but some may be smaller than normal colloid size (normal size of colloid particle is from 1 to 200 $m\mu$). The clay particles are formed mainly of silica. alumina, iron and combined water. Colloidal clay may also contain rich accumulation of plant nutrients. Early researches in soil science have described clay colloids as spherical particles and their sizes were mentioned in terms of their diameters, but recent electron

micrograph reveals that particles occur in layers or plates and each clay particle appears as if it is composed of a large number of plate-like units. These units or flakes of clay are held together by a force of attraction. The plate like clay particles expose large surface area on which moisture and cations (+ions) are held. The finer the clay particles the greater will be the percentage of hygroscopic moisture.

If clay is suspended in distilled water, shaken, and then a little NH_4OH is added to suspension and allowed to settle, after a few minutes large particles settle down but finer particles remain in suspended state. When a little limewater is added to suspension, fine suspended particles increase in size and form small floccules which have a tendency to settle down. Thus, finer clay particles show flocculation property. Now if some acid is added, the floccules are broken and the clay particles will return to their normal size. This process is known as *deflocculation.*

The clay particles are negatively charged, hence they can hold thousands of positively charged ions of mineral nutrients on their surfaces.

The clay colloids are lyophilic (water loving). So they are important from the standpoint of the adsorption of large quantity of water (perhaps 5-10 layers of water molecules are held on the surface of clay colloid).

(2) **Organic Colloids or Humus Colloids**. Organic colloids in the soil are chiefly due to presence of humus. The humus contains 8 % each of lignin, protein, polyuronides (sugars and uronic acid complex). Organic colloids may be present in appreciable proportion in the soils. In sandy soil, it forms major part of colloids. In peaty soil, organic colloids may be more than 50%. These colloids show adsorptive capacity many times greater than clay colloids. Organic colloids are negatively charged like clay colloids. Addition of organic colloids to the sandy soil increases temporarily its moisture and nutrient retaining capacity.

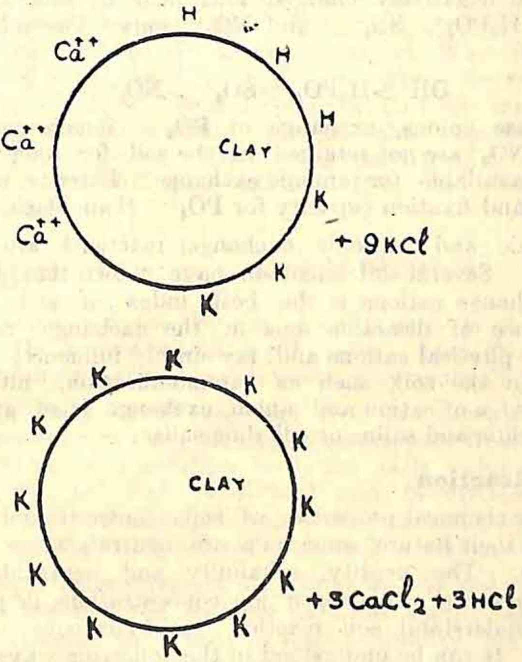
Cation Exchange

Since the soil colloids (clay and organic colloids) have got negative charges on them, they attract and hold positive ions (cations). When cations are added to the soils such as Ca^{++} in the form of lime, K^+ ions in the form of potassium fertilizer, and NH_4^+ in the form of ammonium fertilizer, the adsorption of cations will take place on the surface of colloid micelle and this will be accompanied by release of one or more ions held by colloid micelle. This is known as *cationic exchange.* For example, suppose that colloid micelle has one half of its capacity satisfied with Ca^{++} ions, one quarter with K^{++} ion and remaining one quarter with H^+ ions. Now the colloid is treated with KCl solution. The K^+ ions will first replace Ca^{++} ions and then H^+ ions. The Ca^{++} and H^+ ions will combine with Cl^- ions of KCl and will form $CaCl_2$ and HCl respectively.

The cation exchange in the soil may take place between :

(1) cations present in the soil solutions and those already present on surface of soil colloids,

(2) cations released by plant roots and those present on the surface of soil colloids, and



(3) cations present on the surface of two clay crystals, either two organic colloids or an organic colloid and a clay colloid.

Exchange reaction is very quick and reversible and the exchange of ions continues till equilibrium is attained. All cations are not adsorbed with equal ease. Some are easily adsorbed while others are replaced with difficulty. Divalent cations are more effective than the monovalent ones. Hydrogen is exception because it is held by colloids most tenaciously and it is most powerful replacer of cations. Replacing capacities of some cations are compared here : $H^+ > Ca^{++} > Mg^{++} K^+ > Na^+$.

The number of cations adsorbed per unit weight of one hundred grams dry soil is called 'cation exchange capacity.' More scientifically, cation exchange capacity of soil is the sum total exchangeable cations adsorbed per unit weight of one hundred gms of dry soil.

Factors which are responsible for cation exchange or base exchange are as follows :

(1) relative concentration and number of cations present in the soil,

(2) replacing capacity of the ions, and

(3) number of charges on the ions.

Anion Exchange

Soils rich in organic colloids show anion exchange also. In this process negatively charged ions held by colloids are replaced by OH^-, $H_2PO_4^-$, SO_4^{--}, and NO_3^- ions. The relative order of exchange is

$$OH^- > H_2PO_4^- > SO_4^{--} > NO_3^-$$

Among these anions, exchange of PO_4^{---} ions is most important. SO_4^{--} and NO_3^- are not retained in the soil for long period of time, hence not available for anionic exchange. Laterite soils have high adsorptive and fixation capacity for PO_4^{---} than black soils.

Anionic and cationic exchange reactions are important in agriculture Several soil scientists have shown that the capacity of soil to exchange cations is the best index of soil fertility. The predominance of desirable ions in the exchange complex brings about good physical cations and favourably influences the microbial activities in the soil, such as ammonification, nitrification, etc. The knowledge of cation and anion exchange is of great help in reclaiming acidic and saline or alkaline soils.

(4) Soil Reaction

Many chemical properties of soils centre round soil reaction. As regards their nature, some soils are neutral, some are acidic and some basic. The acidity, alkalinity and neutrality of soils are described in terms of hydrogen ion concentrations or pH values. In order to understand soil reaction, the knowledge of pH is very necessary. It can be understood in the following ways :

Water dissociates into H^+ ion and OH ion. Hence the ionic constant of water can be represented as :

$$\text{Ionic constant of water} = \frac{[H^+][OH^-]}{[H_2O]}$$

But the rate of dissociation of water is so slow that ionization constant of water can be expressed simply as product of concentration of H^+ and OH^- ions, thus ionization constant of water $Kw=[H^+][OH^-]$. Concentration of H^+ and OH^- ions are expressed in terms of equivalents per litre. Only one molecule in ten million water molecules is in dissociated condition.

A neutrality, H^+ concentration is 0·0000001 or 10^{-7} gms of hydrogen per litre solution. The ionization constant of water is 10^{-14} at 25°C and thus in any aqueous system products of H^+ and OH^- ion concentration is 10^{-14}. Now the above equation can be written as :

$$10^{-14} = [H^+][OH^-]$$

This can also be represented in the following way by dividing both sides in one and taking logarithms.

$$\text{Hence } \log 1/\text{Kw} = \log \frac{1}{[\text{OH}^-]} + \log \frac{1}{[\text{H}^+]} = 14$$

The value of $\log \frac{1}{[\text{H}^+]}$ and $\log \frac{1}{[\text{OH}^-]}$ are generally called pH and pOH respectively. These pH and pOH are indices of the acidity and alkalinity respectively. Thus, pH can be defined as negative logarithms of the H+ ion concentration. When the system in neutral, pH will be equal to pOH and when Kw is 10^{-14}, the value of pH and pOH at neutral point will be 7 for each. When pH value is less than 7, it is acidic. The pH value above 7 indicates alkalinity. If in a system, hydrogen ion concentration is 1/·000001 or ·000001 gm/litre, the pH value will be 6. It is more clear from the following calculation :

$$\text{pH} = \log \frac{1}{[\text{H}^+]} = \log \frac{1}{\cdot 000001} \text{ or } \log 10{,}00{,}000 = 6.$$

Thus at pH value of 6, the H+ ion concentration is increased 10 times than the H+ concentration at pH value. Like this, at every lower point H+ ion concentration will increase by multiple of 10.

As the products of H+ ion and OH⁻ ion concentrations at neutrality is always 10^{-14}, the pOH can be determined from pH value. Suppose, pH value of a solution is 6, the pOH value will be 8 ($10^{-6} + 10^{8} = 10^{-14}$). pH scale is divided into 14 divisions or pH units from 1 to 14. Soil with pH value of 7 neutral, that below pH 7 is acidic and that with pH value above 7 is alkaline.

From the pH value intensity of acidity in the soil is expressed but these values are not the measure of total acidity because they do not indicate the reserved acidity or relative acidity. For example, there are two soil samples which have similar pH values but they require different quantities of lime for neutralization. It means that the quantities of acids are different in the given weight of above two soils.

Buffer Action

It refers to the resistance to change in pH of a system. Such solutions as are reasonably permanent in pH value even after addition of some alkali or acid to them are called solution with reserved acidity or alkalinity or more often "buffer solutions". Suppose, a certain amount of acid is added to distilled water, the resulting solution will show acidic reaction and that will have a pH below 7, but if the same quantity of acid is added to a neutral soil suspension there would be very minor change in pH. This property of soil to resist a change in pH is called "buffer action".

Buffer solutions are usually formed of a mixture of salt of weak acid and acid itself in various proportions, as for example, a mixture of sodium acetate and acetic acid if added to water will result in a buffer solution. In the mixture solution, we have mainly sodium ions and acetate ions. In water there will be some H+ and OH⁻ ions. In buffer solution, acetate ions are in excess, owing to presence of well ionised sodium acetate. If H^+ ions are added to this solutions they will combine with acetate ions to give acetic acid of low ionisation power.

$$H^+ + \text{acetate}^- \rightleftharpoons \text{acetic acid}$$

$$K = \frac{[H^+]\,[\text{acetate}^-]}{[\text{acetic acid}]}$$

Hence, there will be a little increase in pH. The addition of acid to buffer solution then makes little difference in the pH value.

Buffering in soil

Soils have got good buffering capacity. Therefore, it is necessary to add considerably large amount of acids or alkalies in order to bring about any change in the original pH of soil. Buffering action is due to presence of large quantity of weak acids and their salts in the soil. Phosphates, carbonates, bicarbonates and other salts of weak inorganic acids and corresponding acids themselves are important buffering agents in the soils. Besides these, colloids associated with cations are important buffering agents. The buffering action of soil is directly governed by the amount and nature of clay and organic or humus colloids present in it.

Buffering action of soil is important in agriculture in the following respects :

(1) *Stabilization of pH* : This protects the higher plants and micro-organisms form direct adverse and injurious effects of sudden change in soil reaction.

(2) *Amount of amendments necessary to correct the soil reaction* : The greater the buffering capacity to soil the larger must be the amount of the amendments (*e.g.*, lime, sulphur, etc.) to correct the acidity or alkalinity.

ACID SOILS

Soils with pH values below 7 are acid soils. In the regions of high rainfall, soils are acidic in their reaction because of the facts that soluble basic salts such as those of Ca, Mg, K, Na are leached away by drainage water and insoluble acidic residues composed chiefly of oxides and silicates of iron, silicon, aluminium are left which accumulate in pretty high amount. These salts are acidic in reaction, hence the soils are acidic. Besides that reason, there may be other causes also which produce acidity in the soil. Important causes which produce acidity in soil are as follows :

(1) Continuous removal of lime and other base elements by crops and accumulation of acids contained in the manures.

(2) Application of acid forming fertilizers in the soil.

(3) Microbial action.

(4) Formation of soil on the acidic rocks.

In India, acid soilso ccur in the high rainfall areas covering about 25 million hectares of land with a pH below 5·5 and 23 million hectares of land with pH between 5·6 and 6·5. These estimates are calculated by Bhaumik, H.D. and Donahue, Roy, L., 1964 (Reference: Soil acidity and the use of lime in India. Farm Information unit, Directorate of Extension, Ministry of Food and Agriculture, Government of India). In India acid soils occur in Assam, Meghalaya, Arunachal Pradesh, Mizoram, Nagaland, NEFA, Manipur, Tripura, West Bengal, Bihar, Uttar Pradesh, Himanchal Pradesh, Jammu-Kashmir, M.P., Maharashtra, Kerala, Karnataka, Tamil Nadu and Andhra Pradesh. Punjab, Haryana, Rajasthan and Gujarat are the only states in India where acid soils do not occur.

Very few plants can grow well in strong acid soils. Soil acidity below pH value of 5·5 is generally injurious to plants. Plant roots are badly affected if the pH value exceed limits of tolerance for particular crops. High degree of soil acidity (pH 5 to 6·5) decreases the availability of plant nutrients particularly phosphorus, calcium, magnesium, molybdenum, iron, manganese, potassium, sulphur, nitrogen, boron, copper and zinc. It also affects adversely the important microbiological processes such as nitrogen fixation by *Azotobacter*, *Clostridium* and nodule inhabiting bacteria (Rhizobia) of leguminous plants.

Origin of Acid Soils

Several factors are responsible for the origin of acid soils. Generally climate, hydrologic cycle, vegetation, parent rocks and human interference play important roles in the origin and development of acid soils. Acid soils occur generally in humid regions where the rainfall is regular and very heavy. Dry regions are devoid of acid soils.

Climate. In humid regions where evaporatation is less than precipitation, chances for the development of acid soils are good. For the development of acid soils it is also necessary that water percolating down the soil profiles must reach the water table. In India, it is believed that the regions with acid soils must receive more than 750 mm annual rainfall. The regions with annual rainfall 1350 mm may have acid soils with pH value 5·0 or even lower than that. In temperate regions the acid soils can develop even if the rainfall is scanty. In hilly regions where the loss of water through evaporation is very slow due to very low temperature the conditions for the development of acid soils are very favourable, although the rainfall is scanty there.

Vegetation Cover. In temperate regions or hilly areas covered with conifers the acid soils can develop easily. According to Bloomfield (1953), the foliage leaves of conifers lack alkali elements and their mineralization process is very slow. When the leaf-litter on the ground is degraded, organic acids are released which gradully make the soils acidic. Plants found in the coastal regions and marshy places after death and decay produce acids which render the soils acidic.

Parental Rocks. Though the development of acid soils is possible on all types of rocks and parental rock materials in presence of favourable climate and vegetation yet the development of acid soils on alkaline rocks take longer time as compared to the acid soils developing on the acidic parental rocks. Acid soils develop more quickly from parental rock materials with simple composition than from the parental rock materials of complex composition. It is so on account of presence of less adsorbed cations, poor buffering capacity and quick percolation of water through them.

Topography. Slopy places with good drainage conditions are supposed to be good for the development of acid soils. On hill slopes the development of acid soils is easy Acid soils do not develop generally in river basins. The plains with good drainage may also develop acid soils in due course of time.

Human interference. Continuous efforts by man in developing permanently submerged areas into cultivable land, or for improving drainage from submerged or saline lands, regular use of nitrogen fertilizers like Ammonium sulphate which cause acidity in the soils are responsible for decrease of soil pH.

In urban areas industrial wastes containing sulphur or sulphur dioxide also contribute much in the development of acid soils.

Classification of Acid Soils

According to the intensity of acidity the acid soils are of the following five types :

(1) Slight acidic (pH range 6·6 to 6·1)
(2) Medium acidic (pH 6·0 to 5·6)
(3) Strong acidic (pH 5·5 to 5·1)
(4) Very strong acidic (pH 5·0 to 4·6)
(5) Extremely strong acidic (pH 4·5 or lower)

Acid soils occurring in different climatic regions are classified as follows :

(i) Acid soils of Temperate climate including Podzol, Brown Podzol, Grey Brown Podzol, Brown forest soils, and Grey forest soils.
(ii) Acid Soil of Tropical and subtropical climates including yellow Podzolic soil, Lateritic soil and Latosols.
(iii) Acid soils of other great soil groups including wet soils (hydromorphic soils), washed peaty soils, Mucky, Cat-clay (acid sulphate soils). Cat-clay or acid sulphate soils with pH 3 5 or lower than that are natural soils. They abound in organic material as well as H_2SO_4.

According to soil classification system (1970) developed by U.S. Soil Scientists, soils of the world have been classified into 10 soil orders. Among these Aridisol, Vertisol and Mollisol are devoid of acid soils and the remaining all 7 orders contain acid soils. But acid soils occur mainly in three orders : Oxysol, Alfisol and Histosol.

In modern soil classification soil orders have been divided into suborders. Suborders *humox*, *Humod*, *Aqualf* and *Udolf* include acid soils.

In modern system of soil classification acid sulphate soils have been assigned separate position and these soils have been placed in a group called *sulpha-aquepts*. This group includes soils in which the top horizon contains sulphuric horizon at some level or the other in top 25 cm thick layer. This is mineral or organic sublayer marked with yellow colouration due to xarocite. Acid sulphate soils of tropics possibly belong to *Typic Sulpha-aquepts* and those of temperate regions are mainly *Typic sulpha aquepts* and *Hapla aquepts*. Mineral and organic soils rich in sulphur which remain regularly submerged are referred to as *Sulphidic soils*. Since such soils develop under the influence of saline water which is rich in sulphur, they are placed in *Halic* subgroup.

Mandal (1974) has classified acid soils of India into the following 7 groups :

(1) Laterite soils
(2) Lateritic and Laterite red soils
(3) Mixed yellow Red soils
(4) Ferringinous Red soils
(5) Podzolic soils
(6) Terai soils
(7) Peaty soils.

In this classification acid sulphate soils and degraded alkali soils have not been assigned proper places. Nevertheless, it would be appropriate if they are classed with acid soils as the pH levels of such soils indicate that they are acidic in nature.

Recently Mishra, S. G. (1976) has suggested that the acid soils should be classified into the following two categories on the basis of organic contents in them :

(1) Acid mineral soils (organic matter less than 20%)
(2) Acid organic soils (organic matter 20% or more)

(1) **Acid mineral Soils.** Such soils are further classified into the following three subgroups :

(*i*) **Acid mineral soils rich in organic matter in upper layer.** Such soils are commonly found in temperate and sub-temperate regions and develop by Podzolisation process. Since these regions are covered with thick forest vegetation, the surfaces of such soils are covered with decomposing organic matter. The degradation of organic matter results in the production of various organic acids, such as citric acid, acetic acid, axalic acid and so on. Microbial degradation of organic matter also produces CO_2 which combines with water to form carbonic acid (H_2CO_3). These acids along with rain water percolate down the soil profiles. Along with these acids and rain water sesquioxides are also leached out from the upper horizons and become deposited in lower horizons. This depletion of sesquioxides from the top layer and their accumulation in lower sublayers is referred to as *Podzolisation* and such soils are called Podzols.

(*ii*) **Acid mineral soils devoid of organic layer**. Acid mineral soils found in plains usually do not possess organic layer. Such soils originate mainly as a result of *laterisation* and partly due to podzolisation process. Laterite soils, Red soils, and hydromorphic acid soils found in India belong to this category. Such soils originate in the following ways :

(a) CO_2 of atmosphere as well as of soil dissolves in water to form carbonic acid (H_2CO_3) which, when percolates down the soil profiles, degrades carbonates and primary minerals present in the soils and makes the soil acidic.

(b) In tropics, at high temperatures maximum degradation of silica takes place and in top soil layer the quantity of sesquioxides increases. This process is referred to as *laterisation*. Laterite and Red loam soils found in India have probably originated through this process.

At low temperatures Yellow Red Podzolic and Grey Podzolic soils originate which are less acidic.

(*iii*) *Degraded Alkali Soils*. The top layer of some alkali soils show a pH value less than 7 due to desalinisation or dealkalization. Such soils are referred to as degraded alkali soils. In this process, the alkali soils are washed by irrigation or rain water and exchangeable Na ions of soils are displaced by H ions of water.

2. **Acid Organic Soils**. According to the amount of organic matter, acid organic soils can be classified into the following two types :

(*i*) Peaty Soils

(*ii*) Mucky Soils

(*i*) *Peaty Soils*. Peaty soils are characterised by presence of poorly degraded organic matter. In India peaty soils occur in Kashmir, Himachal Pradesh, Assam and other states.

(*ii*) *Mucky Soils*. Such soils contain highly degraded organic matter. They have relatively higher pH values than the peaty soils. Thus they are less acidic. Mucky soils are also found in Kashmir, Himachal Pradesh, Assam, and some other states.

Effects of Soil Acidity on Plants

Soil acidity affects the plants both directly and indirectly. These effects are briefly mentioned below :

1. **Direct Influences**. These are as follows :

(a) Toxic effects of low H ion concentrations on root tissues.

(b) Influence of soil acidity on the permeability of the plasma membranes for cations.

(c) Disturbance in the balance between basic and acid constituents through roots.

(d) Affects enzymatic processes since enzymes are particularly sensitive to pH changes. Different crop plants have their specific optimum pH requirement. Rice, oat, and linseed can endure a fairly acidic reaction (pH=5·0) while barley, sugar-beet, lucern etc. can tolerate a fairly alkaline reaction (pH=8·0)

2. **Indirect Effects**. These are listed below :

(a) Availability of various nutrients, e.g., phosphorus, copper, and zinc.

(b) High solubility and availability of elements like aluminium, manganese, and iron in toxic amount due to high acidity in the soil.

(c) Deficiency of some nutrients such as calcium and potassium due to soil acidity.

(d) Prevalence of Plant diseases.

(e) Beneficial activities of soil microbes are adversely affected.

Reclamation of Acid Soils or Correction of Soil Acidity

Acidity of soil is due to predominance of H ions over OH ions, the bulk of H ions being held in close association with clay organic colloid complex. Strong acid soils are not much productive. The soils which are less productive owing to high degree of acidity can be made more productive by liming (applying lime).

When lime is added to moist soil, the soil solution becomes charged with Ca ions and the exchangeable hydrogen and aluminium ions on clay organic colloid complex as well as the H ions in soil solution are displaced by calcium ions. Hydrogen combines with OH to form neutral water or with CO_3^- or HCO_3^- to form unstable H_2CO_3 which readily dissociates to form CO_2 and water.

Acidity of soil can also be corrected by adding exchangeable Mg^{++} to exchange complex. But addition of Ca^{++} or Mg^{++} or both to the soil will not necessarily solve the problem of soil acidity. The important points to be considered in liming are (i) the salts of these elements which are going to supply these ions (Ca^{++} or Mg^{++}) and (ii) the overall reactions of salts in the soils. Salts of strong acids as gypsum ($CaSO_4$) or calcium chloride ($CaCl_2$) can be applied to supply calcium ions to the soils but it is worth considering what will be the effects of these salts on soil acidity. The application of these salts will indeed increase the acidity in the soil, instead of decreasing it. Therefore it is suggested that calcium salts of strong acids must not be applied for correcting the acidity of soils.

Liming materials. More than 90 per cent of the lime used agriculture for reclamation of acid soils is generally in the form of calcium carbonate, some in calcium and magnesium carbonates, and much smaller quantity is in the form of calcium oxide or calcium hydroxide. To chemist lime is calcium oxide but to a farmer, agronomist or Soil Scientists lime usually means calcium carbonate or calcium carbonate equivalents.

The common liming materials used in reclamation of acid soils are as follows :

(1) Calcic lime stone ($CaCO_3$) which is ground lime stone.

(2) Dolomite ($CaCO_3 . MgCO_3$)

(3) Quick lime (CaO) which is burnt lime stone.

(4) Hydrated (slaked) lime [$Ca(OH)_2$]

(5) Coral shell lime

(6) Marl or chalk ($CaCO_3$)

(7) *Slags.* Obtained as by-products from iron and steel plants are used in agriculture for reclaiming acid soils. The slags are of 3 types : (i) blast furnace slags, (ii) Basic slag and (iii) Electric furnace slag. These slags are rich in phosphorus and mixture of CaO and $Ca(OH)_2$. Besides, Ca, Ma, Al, Silicates are also present in them.

(8) *Press-mud.* Obtained from carbonation plants of sugar mills and some other matters containing calcium are used to decrease acidity in the soils.

(9) *Miscellaneous sources of lime.* Such as, wood ash, ground oyster shells, by-product lime resulting from paper mills, tanneries, water softening plants, and by-product $CaCO_3$ from fertilizer factories using gypsum process (such as Sindri Fertilizer Factory, Bihar, India).

The rate of lime application should always be determined after soil testing. When excessive amount of lime are applied to sandy soils low in humus, injury to plants may be caused which may be attributed to one or more of reasons listed below :

(1) Boron deficiency.

(2) Iron, manganes or zinc deficiency.

(3) Availability of phosphorus may be reduced to a critically low level.

(4) Potassium uptake may be reduced.

Such injurious effects may be reduced by application of large amount of manure, green manure crops, compost, phosphorus fertilizers, boron, or a mixture of minor elements.

While applying liming agents to acid soils, the following points must be taken into consideration :

(i) The liming agents should be used in highly powdered state. The smaller the particles of liming agents, the greater will be their effectiveness in correcting the soil acidity.

(ii) Liming materials should be in direct contact with clay organic exchange complex so that H ions exchange complex may be easily displaced by Ca^{++} ions.

(iii) Liming agents should be applied to soils at least one month before sowing the crops or they should be applied thorougly mixed with soils just after harvesting the crops.

Important Roles of Liming agents in Soils

(1) Liming agents reduce soil acidity and stabilize pH of the soils.

$$\text{Acid-clay} + Ca(OH)_2 \longrightarrow \text{Ca-clay} + H_2O$$

(2) Lime makes phosporus more available. This is true mainly because in acid soils phosphorus is fixed by soluble iron and aluminium. Liming reduces the solubility of iron and aluminium and therefore less phosphorus is held in these insoluble and unavailable forms.

(3) Lime makes potassium more efficient in plant nutrition and when K is in sufficient amount plants absorb more potassium than is actually needed but at the same time when lime is available in plenty, plants take up more calcium and less potassium. Economically liming is more desirable because plants absorb more cheap Ca and less of expensive potassium.

(4) Lime enhances the decomposition of organic matter, thereby increases the availability of nitrogen and other nutrients locked up in complex forms to plants.

(5) Lime promotes beneficial activities of soil bacteria.

(6) Liming programme extended over a period of years improves the physical conditions of the soil by causing granulation of soil particles, decreasing its bulk density, increasing its infiltration rate.

(7) Ca and Mg found in liming agents, particularly in Dolomite act as essential elements in the nutrition of plants.

(8) Lime converts toxic elements such as aluminium, Mn, Fe of the soil in insoluble and harmless compounds.

Acid Tolerance in Crops

Some plants are adversely affected and they suffer injuries when grown in acid soils. Familiar crops which can endure fairly acidic soil conditions are oat, rice and linseed and those which are not adapted to acidic soils are wheat, barley, cabbage, *sorghum* (Jowar), tobacco, lettuce, spinach, onion, eggplant or brinjal.

SALINE AND ALKALI SOILS

Saline soils represent a group of soils in which percentages of soluble salts, usually chlorides and sulphates of the alkali bases are very high. The pH of saline soils is always high. In India saline soils occur in many provinces, as U.P., West Bengal, Punjab, Bihar, Orissa, Maharashtra, Tamil Nadu, M. P., Andhra Pradesh, Gujarat, Delhi and Rajasthan covering an area of about 7 million hectares.

There are 4 major tracts in India where salinity problem is very acute. They are (a) the arid tract of Rajasthan and Gujarat, (b) semi-arid alluvial tracts of Punjab, Haryana, and Uttar Pradesh, (c) the arid and semi arid tracts of Southern States, and (d) the coastal alluvium.

In U.P., the saline (usar) soils are distributed in Kanpur, Lucknow, Hardoi, Unnao, Allahabad, Rai Bareli, Azamgarh and many other districts covering about 1·29 million hectares. In Punjab alone saline soil covers about 2 million hectare area. In U.P. and Punjab the saline soils are increasing gradually in area. These lands are known by a variety of names in local agricultural parlance. By far the most common of them is *usar* derived from the Sanskrit word *Ushtra* meaning sterile or barren. Other terms like *reh*, char, *lone thur*, or *shora* are also popular. The word *alkali* is of Arabic origin meaning ash-like and is used to designate hard and intractable soils generally known by the names *rakkar*, *kallar*, *bara* and *bari*.

The salty soils are of three types :

(i) **Saline or Solonchak or white alkali soil**. In this, salinity is caused by soluble salts other than alkali salts. They have high soluble salts and low exchangeable sodium.

(ii) **Alkali or sodic or solonetz or black alkali soil**. This is formed by accumulation of alkalies such as Na, K etc. in excess. Such soils have low salt content but high exchangeable sodium.

(iii) **Saline-alkali soil**. In this alkali and other soluble salts have combined effects. They are also called *saline sodic* as they have high salt content and high exchangeable sodium. The United States Salinity Laboratory (1954) recently designated these soils scientifically on the basis of soil analysis, following the ideas of Sigmond and Gedroiz.

	Saline soil	Alkali soil	Saline-alkali soil
1. Conductivity of saturation Extract (ECe)	more than 4 m mhos/cm at 25°c.	less than 4 m mhos/cm. at 25°c.	greater than 4 m mhos/cm. at 25°c.
2. Exchangeable sodium percentage (ESP)	less than 15	greater than 15	greater than 15
3. pH range	usually below 8·5	between 8·5 and 10	above 8·5

Soils in which salinity is mainly due to accumulation of alkali salts are called alkali soils or usar soils. High alkalinity in the soil adversely affects the plant growth, thereby reduces the crop yield. Such sterile or unproductive soils are called barren soils. The main salts present in the alkali soils are Na_2SO_4, K_2SO_4, NaCl, and KCl.

Types of Alkali Soils. These soils are of two types :

(*i*) Black alkali soils—In these soils, Na_2CO_3 is found in excess.

(*ii*) White alkali soils—In this group, NaCl is in excess.

Russians call such soils as *solonchack*. Bertholet thought that Na_2CO_3 was formed in black alkali soil by interaction of NaCl and $CaCO_3$.

$$2NaCl + CaCO_3 = Na_2CO_3 + CaCl_2$$

Factors which make the soil alkaline

These are :

1. Poor drainage in arid region.
2. Rapid evaporation of alkaline soil solution,
3. Excess uptake of alkaline salts and little percolation.

In arid and semi-arid regions, the rainfall is too low to leach or remove the saline matter from the top soils. Besides this, water along with dissolved alkali salts moves upward by capillary action which on reaching to the soil surface evaporates and the salts accumulate in the form of a hard layer or pan in the subsoil. This hard layer is responsible for impermeability of such soils.

Miller is of the opinion that many plants absorb excess acidic ions, *e.g.*, NO_3^-, than the basic ions. This excessive removal of acidic ions results in the accumulation of basic ions which make the soil alkaline.

According to a chemical hypothesis, alkali soils may result in the following steps :

(a) Reaction between NaCl or KCl and soil (S) :

$$NaCl + S(Soil) \longrightarrow Na\ (S) + Cl^-\ \text{ion}$$

(*b*) then the soluble products are leached away from the soil surface by drainage water, and

(*c*) finally, reaction between insoluble Na (S) complex and carbonates :

$$2\ Na\ (S) + CaCO_3 \longrightarrow \underset{\text{(alkaline)}}{Ca\ (S)} + \underset{\text{(alkaline)}}{Na_2CO_3}$$

Effects of Alkali Salts on Vegetation. The alkali salts show the following effects on plants :

(*i*) Due to excessive accumulation of salts, concentration of soil solution becomes high. This decreases absorption of nutrients by plants and causes plasmolysis of cell cytoplasm in the plants which may be fatal sometimes. All these effects are responsible for stunted growth of plants.

(*ii*) If sodium is absorbed by the plants in excess, it shows toxic effects. Chloride salts of alkaline elements cause the death of trees. $BiCO_3$ and BiCl are toxic to all plants.

(*iii*) Presence of excess salts in the soil retards the germination of seeds and growth of seedlings. Plants die before bearing fruits.

(*iv*) Alkali salts in the soil also affect the plant growth by reducing the size of leaves. In alkali soil, plant roots remain superficial, bark of stem turns brown or black, green tissues are less developed.

Alkali tolerance in Plants. Some plants are resistant to alkali salts. Barley, wheat, oats, *sorghum*, sugar-beet, berseem are best suited to grow in alkaline soil. Cotton, grapes are also alkali tolerants. Uppal *et al* (1961) prepared a list of crops that can be grown at various stages of reclamation and can be categorized as high, medium, and low salt tolerant crops. *High salt tolerant crops* are *Dhaincha*, paddy, sugarcane in *kharif* and oat, berseem, lucerne, sanji (*Trigonella* spp), menthi, and barley in rabi. *Medium-salt tolerant crops* to be tried during second stage of reclamation are castor, cotton, jowar, bajra, and maize for *kharif* and mustard and wheat for *rabi*.

Low salt tolerant crops. Are sesamum moong, urd, arhar, and sannhemp in *kharif* and gram, peas, linseed during rabi.

Uppal *et. al* also listed *babul*, *dhak*, *jhand*, *khair*, *chokra*, *neem*, *Lasora*, *sisum*, siris, *bahera* and *reonjha* as those trees that can be planted on saline alkali soils. The alkal tolerance of plants depends upon :

(*i*) Physiological constitution of cell cytoplasm of the plant ;

(*ii*) Length of roots. Shallow roots are more affected by alkalinity than the deeper roots.

(*iii*) Alkali salts reduce and correct the soil acidity and improve the physical conditions of the soils.

(*iv*) Calcium salts provide calcium to the plants.

(*v*) Many alkali salts change toxic elements, such as Aluminium and Mn into their harmless compounds.

Reclamation of Saline-Alkali Soils

The excessive accumulation of alkali salts in the soils is injurious for plants growth. It is necessary, therefore, to reduce the percentage of salts to optimum or normal level so that plants may grow luxuriantly in such soils. There are several methods of reclamation which can be grouped as follows :

(*A*) Chemical method in which some chemicals are added to the soil in order to bring the alkalinity to desired level.

(*B*) Mechanical practices such as improving drainage and leaching, mechanical shattering of clay pans, and scrapping.

(*C*) Cultural method (growing salt tolerant plants).

Since fundamental causes in various groups of salty soils are different, their reclamly techniques are different. Hence, these are discussed separated.

1. Reclamation of Alkali Soils

Alkali soils are best reclaimed by the following methods :

(A) Chemical Method. (1) By cationic exchange (replacement of alkali from soil colloids by calcium ions). Application of calcium sulphate (gypsum) in the soil reduces alkalinity to a great extent and makes the soil fertile. The reaction proceeds in the following way :

$$2\ \text{Na-clay} + CaSO_4 \longrightarrow Na_2SO_4 + \text{Calcium-clay}$$

$$Na_2CO_3 + CaSO_2 \longrightarrow CaCO_3 + Na_2SO$$

Good drainage leaches away N_2SO_4.

(2) Alkali salt percentage can also be reduced in the soil by the use of acid forming chemical amendments such as sulphur, ferrous-sulphate, limestone. Sulphur, when applied in the soil, oxidises and forms sulphuric acid which converts carbonates of sodium and potassium to Na_2SO_4 and K_2SO_4 respectively that may be removed from top soil by drainage water.

The amount of gypsum and sulphur required to reclaim the alkali soils will be different depending upon the degree of alkalinity, drainage, and buffering capacity of soils.

The types of reaction which occur when an amendment is applied to an alkali soil are given below.

(1) **with Sulphur**.

(*i*) $2S + 3O_2 = 2SO_3$

(*ii*) $SO_3 + H_2O = H_2SO_4$

In the next step, if soil is calcareous—

(*iii*) $H_2SO_4 + CaCO_3 = CaSO_4 + CO_2 + H_2O$

(*iv*) $2Na\text{—}Clay + CaSO_4 = Ca\text{-}Clay + Na_2SO_4$

But if the soil is non-calcareous—

(*iii*) $2Na\text{—}Clay + H_2SO_4 = 2H\text{—}clay + Na_2SO_4$

(2) **With Lime-Sulphur.**

(*i*) $CaS_5 + 8O_2 + 4H_2O = CaSO_4 + 4H_2SO_4$

Now if the soil is calcareous—

(*ii*) $H_2SO_4 + CaCO_3 = CaSO_4 + CO_2 + H_2O$

(*iii*) $2Na - Clay + CaSO_4 + Ca\text{—}Clay + Na_2SO_4$

But if the soil is non-calcareous—

(*ii*) $2Na\text{--}Clay + 4H_2SO_4 + CaSO_4 = 8H - Clay + 5\ Na_2SO_4$

(3) **With Ferrous Sulphate.**

(*i*) $FeSO_4 + H_2O = H_2SO_4 + FeO$

Now if the soil is calcareous—

(*ii*) $H_2SO_4 + CaCO_3 = CaSO_4 + CO_2 + H_2O$

(*iii*) $2Na\text{—}Clay + CaSO_4 = Ca\text{—}Clay + Na_2SO_4$

But if the soil is non-calcareous—

(*ii*) $2Na\text{—}Clay + H_2SO_4 = 2H\text{—}Clay + Na_2SO_4$

(4) With limestone on non-calcareous Soils.

(*i*) $Na-Clay+H_2O=H-Clay+NaOH$

(*ii*) $2H-Clay+2NaOH+CaCO_3=Ca-Clay+Na_2CO_3+2H_2O$

With any H—Clay :

(*i*) $2H-Clay+CaCO_3=Ca-Clay+CO_2+H_2O$

The use of pyrite (FeS_2) as an amendment is a recent development in the chemical amelioration and reclamation of alkali soils. In presence of moisture and air, pyrite is converted into sulphuric acid which then replaces exchangeable sodium by Hydrogen or calcium dissolved from insoluble calcium present in the soil. In addition it is said to correct iron deficiency and lime induced iron chlorosis in alkali soils. It is important to mention that the formation of H_2SO_4 in the soil by the application of pyrite may take place through chemical and microbiological action, Pyrite is oxidised according to the following equation suggested by Bloomfield (1973).

$FeS_2+2Fe^{+3}=3Fe^{+2}+2S$ (Chemical)

Sulphur thus formed could be the substrate for *Thioxidans* which converts it into H_2SO_4.

$S+3\ (O)+H_2O=2H^+SO_4{}^{-2}$

Temple and Kochler (1954) explained the action of :

I. *ferroxidans* on the formation of H_2SO_4 as follows :

$FeS+H_2O+7O=FeSO_4+H_2SO_4$

$2FeSO_4+O+H_2SO_4=Fe_2(SO_4)_3+H_2O$

$FeSO_4$ formed in the above reaction may be converted into H_2SO_4 by hydrolysis.

$FeSO_4+H_2O \longrightarrow H_2SO_4+FeO.$

In brief, the pyrite is oxidized in soils to ferrous sulphate and sulphuric acid as depleted in the following equation :

$2FeS_2+2H_2O+7O_2=2FeSO_4+2H_2SO_4$

Both sulphuric acid and ferrous sulphate help in reclamation of calcareous as well as non-calcareous salt affected soils by lowering the pH and solubilising calcium from free calcium carbonate present. The reactions are given below :

Salt affected calcareous Soils

Ia. $CaCO_3+H_2SO_4=CaSO_4+CO_2+H_2O$

Ib. $2Na-Clay+CaSO_4=Ca-Clay+Na_2SO_4$

II. $FeSO_4+H_2O \longrightarrow FeO+H_2SO_4$

H_2SO_4 formed in reaction II reacts as per equations Ia and Ib

III. H_2SO_4 also neutralizes $NaHCO_3$ and Na_2CO_3 present in these soils.

$2NaHCO_3+H_2SO_4 \longrightarrow Na_2SO_4+2H_2O+2CO_2$

$Na_2CO_3+H_2SO_4 \longrightarrow Na_2SO_4+H_2O+CO_2$

But if the soil is non-calcareous.

(*i*) $2Na-Clay+H_2SO_4=2H-Clay+Na_2SO_4$

(*ii*) $FeSO_4+H_2O=FeO+H_2SO_4$

H_2SO_4 formed in reaction II acts in similar manner as in reaction I.

(3) *Dhar's method*. In India, Dr. Neel Ratan Dhar (1935) succeeded in reducing the alkalinity and salinity of the soil by the use of molasses (Hindi—raab) and press mud. For one acre land he recommended the mixture of the following substances :

(*i*) 2 tons of molasses, (*ii*) 1-2 tons of press-mud (a waste product of sugar industry) and (*iii*) 50-100 pounds of P_2O_5 in the form of basic slag.

The molasses is fermented by soil microbes and as a result of fermentation organic acids are produced which lower the alkalinity and increase the availability of phosphates. The press-mud contains Ca which forms calcium salts that reduce the content of exchangeable sodium. Phosphate helps in the fixation of nitrogen into nitrogenous compounds in the soil.

(B) **Mechanical Method.** The alkali salts are removed by

(1) scraper or by rapidly moving streams of water,

(2) deep ploughing of the land which also reduces the alkalinity and makes the soil more permeable,

(3) application of green manures of *Dhaincha*, guar, jantar (*Sesba nia aculeata*) has been found most successfull in reclamation of alkali and saline soils.

(4) spreading of straw and dried grasses and leaves on the alkaline soil.

(**C**) **Cultural Method**. Growing of alkali tolerant crops and plants such as sugar-beet, rice, patsann (*Hibiscus cannabinus*), wild Indigo, and babul in such soils successfully reduces alkalinity. Rice is commonly the first crop grown on salty lands to be reclaimed. In Punjab, the usual practice of reclamation of salty lands involves growing of paddy after first initial leaching, followed by berseem or senji which has higher water requirement, than *Dhaincha* as green manure which is followed by sugarcane and then wheat or cotton. Introduction of leguminous crops helps building up of nitrogen supply and opens the soils. *Dhaincha*—paddy—berseem rotation has been found to be the best cropping pattern on mild type of alkali soils in Punjab region. In U. P., paddy alone or *dhaincha* paddy are the usual crops taken, during first stage of reclamation of Salty Soils. This is followed by berseem or barley in winter. Pulse crops like gram or peas show poor performance.

II. Reclamation of saline soil. Saline soil can be reclaimed by the following methods :

(1) By lowering the water table 5-6 feet below the surface. In slopy area it can be done by making network of 5-6 feet deep trenches at right angles to the slopes. In course of 2 or 3 succes-

sive leaching, harmful salts are removed. A deep ploughing is also helpful in reclamation of saline soil. This also makes the soil loose and thus facilitates the downward movement of salty water in the soil.

(2) Salt tolerant crops, *e.g.*, rice, sugarcane, barley and castor gradually remove salts from the soil.

(3) In case of saline soils which do not contain calcium salts, the addition of $CaSO_4$ (gypsum) is beneficial. Supply of calcium in the soil can indirectly be maintained by addition of organic matters which on decomposition produce CO_2. The CO_2 gas, thus produced, combines with insoluble calcium carbonate in moist condition to form soluble calcium bicarbonate. This also reduces alkalinity.

(4) Application of green manure, organic manures, organic residues, acids or acid formers is yet another good way to reduce salinity.

III. Reclamation of Saline-alkaline soil. Here the problem of reclamation is two-fold because of

(*a*) heavy accumulation of different types of salts,

(*b*) poor percolation due to the presence of hard clay pan and highly dispersed sodium clay.

Such soil can be reclaimed by ;

(*i*) *Mechanical shatterning of clay pans.* This helps in downward movement of water ;

(*ii*) *Application of gypsum in the soil.* This is followed by flushing with plenty of water :

(*iii*) *Green manuring* with Dhaincha (*Sesbenia aculeata*) ;

(*iv*) *Growing salt tolerant plants e.g.*, paddy in kharif and oat and barley in rabi seasons are recomended for such soils.

Schoonover (1959) worked on the soils of India and enlisted the following technical requirements for reclamation of saline and alkaline soils :

(1) Necessity of good drainage.

(2) Availability of sufficient water to wash the excess salts from the top soils.

(3) Good soil management including land levelling, good bunding for irrigation and recent and advanced agronomic practices.

(4) Protection of soil from erosions.

(5) Good quality of irrigation water.

QUESTIONS

1. **Discuss in brief chemical properties of soil.**
2. **Give a brief account of physical properties of soil.**
3. **Write short notes on : (*i*) soil pH , (*ii*) ionic exchanges in the soil. (*iii*) Buffer action.**
4. **Discuss the origin, classification and effects of acid soils and mention the methods of reclamation of acid soils.**
5. **What are the different types of salty soils and how do they originate ? Discuss the various methods of reclamation of alkali soils, saline soils and saline alkaline soils.**

18

PRINCIPLES OF SOIL CLASSIFICATION AND SOIL SURVEYS AND CHIEF SOIL TYPES OF INDIA

CLASSIFICATION OF SOILS

Soils are of various types as regards their physical, chemical and biological properties. Soil samples collected from distant places and from different climatic regions may show considerable resemblances and differences in their physical, chemical and biological properties. In order to make the study of soils convenient, soils are classified into well defined categories. The classification of soils, in brief, aims mainly at the orderly and systematic arrangement of soils on the basis of resemblances and differences in their physical, chemical and biological properties. As in biological systems plants and animals are classified into classes, orders, suborders, families, etc., similarly soils are also classified into well defined classificatory units as orders, suborders, great soil groups and subgroups. Lower classificatory units in the soil classification are families, series, types and phases.

Soil orders

These are the largest categories. They are described into the following groups :

(a) **Zonal soil**. This is characterised by well differentiated profile. Soil develops on well drained parental rock where environmental factors are little active.

(b) **Intrazonal soil**. In this group, soil shows well differentiated profile which may be influenced by climatic and biological factors.

(c) **Azonal soil**. It is characterised by the absence of profile. Soil may be in the formation stage and it may be either too immature or may be subjected to extreme environmental influences. Such soils are formed on rocky slopes or on steeps in the form of alluvial deposits, coarse sand deposits, etc.

Sub-orders of soils

These are recognised on the basis of factors that influence soil formation and the distinguishing features of soil groups itself, as for example cold and arid soils are direct products of climatic conditions. Similarly, grassland, transitional land and forest soils are products of combined effects of climates divided into great soil groups.

Soil Series

It consists of a group of soils with similar profile differentiation and similar horizon characteristics such as colour, thickness, structure, reaction, and approximate organic contents. Textures of surface soils are not taken into consideration in the recognition of soil series. Soil series are usually named after town, river or other geographic places near which they are first identified, for example, Miami series which was first recognized in Miami river shades in Ohio (U.S.A.).

Soil Types

These are subdivisions of soil series. They are recognised on the basis of soil texture. The names of soil types are given after series names and the terms describing texture of the surface soils, for example, Indogangetic alluvial soil where Indogangetic plains are the places of occurrence and alluvium is the texture of surface soil.

Soil Phase

Soil types are sometimes further divided into phases on the basis of slopes, stonyness, degree of erosion and surface characteristics.

In classification of soil the following descending sequence is followed :

Order
Suborder
Great soil group
Series
Soil type
Soil phase

Some Soil Classifications

Middelburg, H.A., proposed a tentative scheme of classification for tropical and subtropical soils (Reference : Transactions; Fourth International Congress of Soil Science, part 4 : 139-147). The scheme is as follows·

Order	*Sub-orders*	*Great soil groups*
Zonal	(1) Humid regions	(1) Podzolic yellow soil with black humic top soils
		(2) Red yellow podzolic soils
		(3) Non-laterised red soils
		(4) Laterised red soils
		(5) Degraded grey and black clay soils
		(6) Illuvial soils
	(2) Arid region (Desert soils)	(1) Red desert soil
		(2) Dark desert soil
Intrazonal	(1) Calcimorphic (Calcareous soils)	(1) Red soil (developed over lime stone)
		(2) Black soil (developed over lime stone)
		(3) Red soil (developed over marls)
		(4) Black soils (developed over marls)
	(2) Halomorphic	(1) Saline soil
	(3) Hydromorphic soil	(1) Ground water lateritic soil
		(2) Planosols
		(3) Organic soil
Azonal	Lithosols	
	Regosols	
	Alluvial soil	

On the basis of properties of soils, recently a new system of soil classification has been propsed by E. Joseph Larsen (Soil Conservation, 30, No. 5, Dec. 1964). The scheme has now become official classification system for United States Department of Agriculture (USDA) from January 1, 1965. Brief outline of this classification is given below :

Order	*Meaning*	*Approximate equivalent soil groups in Asia*
1. Entisol	Recent soil	Alluvial soil, Regosols
2. Vertisol (Latin *Verto* = turned)	Inverted soil	Granulosols
3. Inceptisol (*Inceptum* = beginning)	Inception or Young soil	Andosols
4. Aridisol (Latin *Aridus* = dry)	Arid soil	Desert soil
5. Mollisol	Soft soil	
6. Spodosol (Gk. *Spodos* = woodash)	Ashy soil (Podzol) Ledalfer	Podzol
7. Alfisol	(Al-Fe) soil	
8. Ultisol (Latin *Ultimus* = last)	Ultimate of leaching	Noncalcic, brown soil, Red brown soil, Grey hydromorphic soils, Red yellow, Podzolic soils, Grey podzolic soils
9. Oxysol	Oxide soils	Latosols
10. *Histosols* (Gk. *Histos* = tissue)	Tissue soils Organic soils	Organic soils

SOIL SURVEY

Soil survey is study and mapping of soils in the fields. It is starting point for all soil researches. The following are the main objectives of soil survey :

(1) To describe and classify soils given uniform system of classification with uniform nomenclature in order to correlate the soils of different area.

(2) To show distribution of different soils in the field (soil mapping).

(3) To provide data for making interpretations as to the adaptability of particular soils for agriculture purpose and also for many other purposes (as in soil management). Soil surveys are of the following three types :

(1) Detailed

(2) Reconnaissance

(3) Detailed reconnaissance

1. Detailed Soil Survey

In this, soil boundaries are plotted accurately on maps on the basis of observations made throughout the surveyed area. In this, geographical distribution of soil is also described. Detailed soil surveys are important in the sense that they provide informations needed for planning land use and management and formulating agricultural research and extension programmes.

2. Reconnaissance Survey

In this, soil boundaries are plotted from the observations made at intervals.

3. Detailed Reconnaissance Survey

In this, a part of surveyed area is plotted on the map by detailed method and remainder by reconnaissance method. In mapping of soils either aerial photographs are taken or good topographic maps are made.

In mapping of cultivated areas, generally a scale of four inches to a mile is used but detailed or special maps are made on scales of six inches, eight inches or twelve inches to a mile. In India, soil surveys are being carried out by central and provincial agencies. Some surveys of limited areas have been conducted for specific objectives such as fertility surveys, surveys for soil classification, survey from geological point of view, from physiochemical properties of surface sample and surveys for genetic classification. Pre and post-irrigation surveys have also been used for limited areas under command of big irrigation projects to determine the nature and quality and the concentration of soluble salts in different horizons of soil. In India, a few generalized soil maps have been prepared under the auspices of International Society of Soil Science. The Geological Survey of India and the I.A.R.I. (Indian Agricultural Research Institute), New Delhi. The latest soil map of India is given in figure 15·1.

CHIEF SOIL TYPES OF INDIA

Depending upon the mode of origin, soils can be classified into two main groups :

(*i*) Sedimentary or residual soils

(*ii*) Transported soils

(*i*) **Residual Soils**. These soils are formed from the disintegrated rocky material and remain at the same places where they are formed.

(*ii*) **Transported Soils**. These are shifted soils and are brought from one place to another by various agencies. They are of different types such as :

(*1*) *Illuvial soils* :—Soils that move due to gravitational influence.

(2) ***Alluvial soils*** :—Soil is brought by running water.

(3) ***Glacial soils*** :—Soil is brought or transported to a particular place by glaciers.

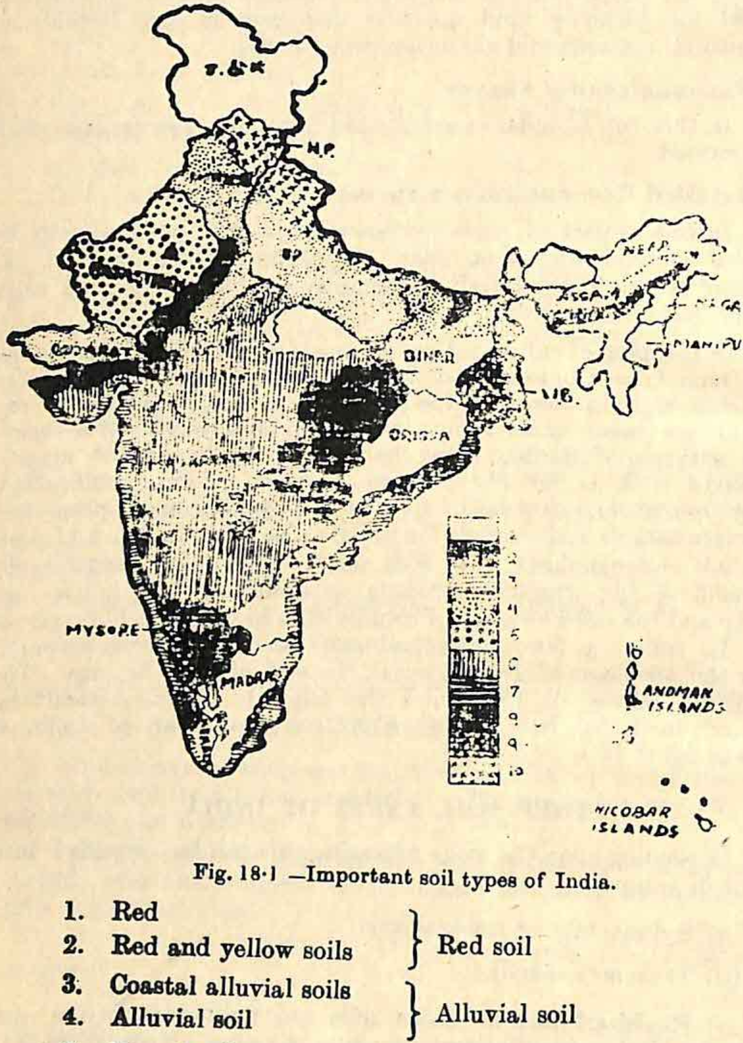


Fig. 18·1 —Important soil types of India.

1.	**Red**	**Red soil**
2.	**Red and yellow soils**	
3.	**Coastal alluvial soils**	**Alluvial soil**
4.	**Alluvial soil**	
5.	**Desert soil**	
6.	**Shallow black soil**	**Black soil**
7.	**Black soil**	
8.	**Peat soil**	
9.	**Laterite soil**	
10.	**Mountain or Scanty soil**	

(4) *Aeolian soils* :—Wind moved soils, *e.g.*,

(1) Dune sands of variable fineness,
(2) Volcanic ash,
(3) Loess, silt like material.

Geographically soils of India are divided into three groups :

(*i*) Mature soils of Peninsular India (include red soils, black soils, lateritic soil).
(*ii*) Alluvial soils of Indogangetic plain,
(*iii*) Scanty soil of Himalayas.

soils of India are classified into the following main groups :

(1) Laterite or Lateritic soils,
(2) Black cotton soils or 'regur',
(3) Red soils including red loam, yellow earths etc.,
(4) Alluvial soils including deltaic coastal and inland alluvium,
(5) Alkali soils and saline soils,
(6) Peaty and other organic soils of forests,
(7) Desert soils or arid soils,
(8) Scanty soils of mountains and hills.

1. Laterite or Lateritic Soil

Laterite is generally reddish or yellowish red in colour which turns black on exposure to sun. This group of soil occupies belts of various widths around the peninsular zone. Such soils occur on the plateau of Malwa, Madhya Pradesh, Central India, Bihar, Orissa, Tamil Nadu, Eastern and Western Ghats, Assam, Bengal, Hyderabad covering a total area of about 2,48,000 square kilometres.

Origin of lateritic soils is still a matter of dispute. According to some soil scientists, the rocks rich in aluminium can produce such soils. Important rocks which produce such soils are *greisze*, sand stone, basaltic rocks and granite. Laterites are formed in the region of high rainfall and with alternating wet and dry seasons. These are residual or sedimentary rocks. When the alkali and silica are leached away the residual compounds rich in aluminium and iron oxides form such soils. Lateritic soils are compact and composed of hydrated oxides of aluminium and iron with small amount of manganese and titanium oxides. When soil is broken and carried to lower levels by water it again becomes cemented into compact indurated honey-combed mass.

Lateritic soil is usually poor in lime, magnesia, nitrogen, phosphate, and potash. Humus is present in abundance in this soil. Base exchange capacity is low. Soil is good for agriculture purpose. Valley soils can produce good crops of rice and sugar cane.

2. Black cotton soils or Regur

(*Regada=Black*)

These soils are black in colour and best suited for cotton cultivation. It is locally known as regur in some provinces. Black soils are distributed in Tamil Nadu, south-east Bombay. eastern Hyderabad, Maharashtra, Western M.P., parts of Mysore, Andhra Pradesh, Gujarat, southern districts of Orissa, Bundi and Tonk districts of north Rajasthan, and Bundelkhand region of U.P. covering total area of approximately 5,46,000 square kilometres. The soil is derived from Deccan and Raj Mahal trap rocks and ferruginous gneisses and schists in Madras.

According to Theofold, the black soil is associated with Deccan trap. Apparently, it is derived by the decomposition of trap rocks and blackish colour is due to presence of superficial iron in the rocks.

According to Hislop, it is of subaerial origin or it has been formed by the alternate deposition of organic soil and the primary deposition of weathering products of almost all the rocks. According to some other workers, it is produced by assimilation of humus of different argillaceous soils derived from the decomposition of trap rocks.

According to Ramaswamy Sivan, it is formed due to accumulation of black colured light soil particles. The surface fraction consists of small transparent or semi-transparent grains cemented together by dark coloured matrix which is a double hydrated ferrous and aluminium silicate.

The colour of regur soil varies from place to place. Regur soils are mostly dark grey to black in colour. The soil is clayey (clay content 40—60%) and loamy. The soil is characterised by high percentage of calcium and magnesium carbonates, iron oxides and alumina. It is sticky in wet condition and contracts on drying resulting in cracks or heavy fissures. The soil is poor in phosphorus and rich in nitrogen and organic matter.

Black soil is very productive. Water retaining capacity is much high. The base exchange capacity is also very high. Among the crops, cotton is the best suited. Other crops suited to black soils are wheat, millet, gram, pea, etc. The soil requires proper irrigational facilities. Black soils have been categorised into different groups which are based upon the depth of their formation. These groups are :

(i) **Shallow black soils (Depth ranges from 30 to 50 cms).** These soils are derived from basalts of Deccan trap.

(ii) **Medium black soils (Depth ranges from 50 to 120 cms).** They are derived from a variety of rocks including basaltic trap, Dharwar schists, basic granites, gneisses, Hornblende and Chlorite schists.

(iii) **Deep black soil (Depth ranges from 120 to 200 cms).** These are derived from basaltic traps in Deccan plateau and are commonly identified as "regur soils". Distribution of irregular nodules of lime (Kankar) throughout is regular feature of this sub-group of black soil.

3. Red soil including Red loam, and Yellow earth

These soils are distributed in India mainly in the peninsular regions. The soils occur mainly in M.P., S.E. Bombay, Mysore, Andhra Pradesh, West Bengal, Assam, Orissa, Chhota Nagpur covering a total area of about 3,50,000 square kilometres. Red soils are also found in some parts of Bihar and in Mirzapur, Hamirpur, Banda and Jhansi districts of U.P. and territory of East Aravali hills in Rajasthan.

These red soils develop from metamorphic sediments of granite gneisses and schists.

The red soils of valleys and plains are dark and fertile. These are composed of silica and aluminium with free quartz of sands. Soils are low in bases and base exchange capacity. These soils are characterised by absence of lime nodules (Kankars). Percentages of humus and other organic nutrients are very poor in red soil. Ferrous oxide is precipitated after evaporation of water from the soil. They are neutral to acidic in their reaction. Soils are generally rich in potash but nitrogen content is low. The red soils are light, friable and porous. Their water absorbing capacity is very low. Cultivation on such soils depends upon irrigation and rainfall.

4. Alluvial soils including deltaic coastal and inland alluvium or Alluvial soils of Indogangetic plains and river basins

It is the largest soil group in India covering a total area of about 15,00,000 square kilometres. Soil is distributed in parts of Rajasthan, Punjab, U.P., Bihar, West Bengal and Orissa.

The soil is best suited for agriculture provided rains occur regularly. Alluvial soils are suitable for cultivation of wheat, rice, cotton, maize, millet, oils, sugarcane, vegetables and jute.

The various kinds of alluvial soils have same origin. They are formed from the materials transported by rivers over long period of time. The soils are found in the valleys of Brahmaputra in Assam ; Narbada and Tapti rivers in M P.; Godawari, Krishna and Kaveri in the south; Jamuna, Ganga and their tributaries; Gandak, Gomati, Ghagra and others in U.P.

The soils are immature and can be divided into two geological groups, namely, old and new alluvial sub-divisions. The old alluvial soils, also called 'Bangar', are the soils of high lands and are composed of massive clay or compact silt. These are mixed with sands and kankars or lime nodules and are pale brown or dark in colour. The old alluvial soils are in the process of denudation. The new alluvial soil group, also known as *Khadar*, is sandy with less kankars. It is light in colour.

The soil of dry regions are rich in K, P, and alkalies. CaO and FeO are present in varying amount. In Brahmaputra and

Ganga velleys and in Assam plains, the great *Khadar* is low in lime, K, and Mg content.

In dry regions of India, alluvial soils contain KNO_3 and alkali in excess. Scanty rainfall, high temperature and natural drainage are chief conditions which result in the accumulation of salts in the form of underground obstructions and impervious clay pans which inhibit the leaching. These factors are also responsible for the development of barren land (usar) which is useless for cultivation.

The deltaic soils of Ganga and Brahmaputra are rich in humus and are loamy, and hence they are fertile. But by floods, surface soils are removed and also replaced by fresh silty soils. This reduces the soil fertility. Alluvial soils of peninsular regions including those of Narbada and Tapti valleys are very fertile. In eastern ghats, the deltaic soils of Godawari, Krishna and Kaveri rivers are black, humid and sandy. The soils of Orissa are sandy and swampy with fine texture. They are rich in potash.

Soils of Madras transported by rivers and consist of alternate layers of sands and silts. The alluvial soils of Gujarat, locally known as *Goradu*, consist of brown clay and *kankars*. Soils are poor in organic contents and nitrogen but rich in potash. This type of soil is very common in north Gujarat and Ahmedabad.

Yellow and red alluvial soils of M.P. are found in the basin of Mahanadi river covering Balaghat, Durgapur, Raipur and Bilaspur districts. These soils are grouped as *Bhata*, *Matasi*, *Dorsa*, and *Kanhar* as these are found at different altitudes.

Bhata is barren soil consisting of red gravels and sands. This is found on uplands.

Matasi is yellow loamy clay soil.

Dorsa is dark coloured clay soil of slopess.

Kanhar is darker and heavier than *Matasi* and *Dorsa* and is deposited in low lying areas.

The alluvial soils of U.P. are divided into the following four regions :

(*a*) Alluvial soil of West and North U.P. (light texture)

(*b*) Alluvial soil of East U.P. (heavy texture)

(*c*) Alluvial soil of Central region (soil consists of old alluvium which is neither too light nor too heavy, *i.e.*, this is intermediate in texture).

(*d*) Alluvial soil of northeast U.P. (it contains $CaCO_3$ and other salts and shows alkaline reaction).

5. Alkali and Saline Soils

In these soils, percentage of salts is very high. These soils are distributed in Kanpur, Lucknow, Hardoi, Unnao, Raibareli, Azamgarh and many other districts of U.P., Punjab, West Bengal, Bihar, Orissa, Maharashtra, Tamil Nadu, M.P., A.P., Gujarat and

Delhi covering an area of about 7,000,000 hectares. Some soils are salty mainly due to presence of alkali salts in them. They are called alkali soils. In some soils salts other than alkali are present. These are commonly referred to as saline soils or non-alkali saline soils. Alkali soils are barren and are also called usars in Hindi.

Detailed accounts on saline and alkali soils have been given in the chemical properties of soils.

6. Peaty and other organic soils of forests

Peaty soils are also known as peaty saline soils. At some places it is called *Kari*. The peaty soils are peculiar blue coloured soils. The waterlogged peaty soils appear in the low lying submerged areas. They are also termed as marshy soils. The peculiar colouration is due to presence of free aluminium ferrous compounds. Organic matters are accumulated in poorly decomposed conditions on account of the lack of oxidation and poor drainage conditions. Peaty soils are distributed in coastal tracts of Orissa, West Bengal (in Sunderban), North Bihar, Almora in U.P., S. E. Tamil Nadu and Kerala covering an area of about 150 square kilometres. Soils are rich in humus and are acidic. Sometimes water soluble alkali salts are also accumulated in the soils. During monsoon period soils are flooded with water.

7. Desert soils or arid soils

Desert soils are commonly found in arid and semi-arid zones in India, *e.g.*, North Western Rajasthan and South Punjab (between Indus river in west and Aravalli hills in the east) covering a total area of about 1,42,000 square kilometres. In arid area, rainfall is very poor (up to 62·5 cm.) and temperature goes very high in the summers. The soils in these areas are coarse textured regosols and wind moved sand and sand-dunes. Soils are salty and they contain good amount of alkalies, and humus content. Their water holding capacity is very low. At several places due to poor rainfall soils become barren but they can be reclaimed to normal conditions provided irrigational facilities are available. The scarcity of water and excessive accumulation of salts make the soils unfit for cultivation. This is why vegetation is very poor and forests are totally absent and desert is spreading progressively eastward in Rajasthan.

Considerable attention is being given these days for checking desert and for converting the desert land into fertile area. Recently Central Arid Zone Research Institute, Jodhpur, has recommended the stabilization of sand by growing thick vegetation in the area. Central Arid Zone Research Institute has further recommended the cultivation of many indigenous and exotic varieties of trees, grasses and salt tolerant species which grow in desert conditions. Important plants well suited to desert land are *Calligonum polygonoides*, *Leptadenia*, *Crotolaria*, some grasses and herbs such as *Citrulus*, *Rhynchosia*. Some trees of deserts are *Prosopis*, *Acacia*, *Albizzia lebbeck*, *Dalburgia sissoo*, *etc*.

8. Scanty Soils of Hills and Mountains

Mountain or hill soils are distributed in India from northwest to eastern part of the country up to 20,000 feet altitude. At high altitudes, entire soil surface is covered by snow. Mountain and hill soils are loose and are young or immature. In these soils, a horizon is formed on the surface of rocks directly. Soil particles are loosely aggregated in soft sandy beds. The scanty soils may be of two types :

(1) acidic soils with acidic humus.

(2) basic soils having high base status.

In foothill areas of Kumaon and Garhwal districts, soils are coarse and gravel type mixed with clay and iron salts. In these areas at the altitude of 5,000 to 11,000 feet sal forest and pine forests are common. Important crops grown on such soils are wheat, maize and tea. The soils of hilly regions of Assam and Darjeeling contain high degree of organic matter, nitrogen and minerals. These soils are acidic in reaction.

The Himalayan region of U.P. consists of soils known as 'Bhabar', 'Terai' and 'Plains'.

The soils of Himachal Pradesh may be divided into low, mid and high hill soils and mountain soils.

The Himalayan soils can further be divided into the following soil groups on the basis of distribution and types of vegetation.

(i) **Terai soils**. It is distributed near foothills of Simla. Soil is clayey in composition and has got high water retaining capacity and humus content. Hence, it is very fertile.

(ii) **Tea soils.** These are found in Assam, Dehradun, and Darjeeling. Soils are light loamy with low lime contents. Rainfall is extremely high. Soils are well suited for the plantation of tea.

(iii) **Igneous soils**. This soil is derived from granite rocks. It is fertile and good for cultivation purpose.

(iv) **Soils of older rocks**. Such soils are found in Nainital. They are rich in clay and iron contents thus suitable for cultivation of certain crops and vegetables.

(v) **Lime stone soil.** It occurs near Mussoorie. Rice is the main crop of this hill soil.

QUESTIONS

1. Give an account on soil classification and soil surveys.
2. Describe the main soil groups found in India and mention the distribution and properties of each group.
3. Discuss the distribution and properties of (*i*) arid, and (*ii*) scanty soils of hills and mountains.

19

SOIL EROSION AND SOIL CONSERVATION

Soil is a store house for organic, and inorganic plant nutrients and water. Some soils are rich in organic and humus contents and are more productive while others are less productive and have very poor percentage of organic contents. The soil is subjected to a continuous and simultaneous depletion (or loss) and addition of soil resources. The various soil components are being removed by living organism and are returning to the soil by way of death and decay of organisms on it. If the rate of removal or loss of components is greater than the rate of addition, the soil will naturally become less fertile. The various factors which make the soil less fertile are :

(1) Leaching

(2) Biological agencies

(3) Soil erosion.

Leaching is an important factor which makes the soil poor in its resources. In this process, minerals and organic substances are removed from the top layer of soil by rain water.

Biological agencies are also active in causing loss of resources from the soil. Cultivation of crops regularly year after year makes the soil less productive. In cultivation there are little chances for the compensation of lost nutrients in the soil by way of death and decay of the vegetation which grows on it. Leguminous plants, however, compensate the loss of nitrogenous compounds because bacteria inhabiting in their root nodules fix considerable amount of free atmospheric nitrogen into its compounds such as nitrites, nitrates, ammonia and so on.

SOIL EROSION

The word 'erosion' literally means *to wearing away*. In soil erosion, fertile soil surfaces are detached and removed from their original places and are deposited at some other places. According to Fox (1950), "the term soil erosion covers a wide range of physical and chemical actions such as removal of soluble matters, chemical changes, disintegration by frost or by rapid changes of temperature, attrition by dust charged wind, scouring by silt laden currents, alternate impact and succession by storm waves, landslides, and so on". Thus soil erosion is the removal of soil from its upper part.

There are two main types of erosions, namely (1) *normal erosion* and (2) *accelerated erosion.*

1. Normal Erosion

When the top soils are gradually removed in nature under normal conditions of physical, biotic and hydrological equilibria it is called normal erosion. Sometimes, it is also called geologic erosion. It is very slow process in which complete equilibrium is maintained between soil removing and soil forming processes. The normal erosion tends to produce wavy or undulating land surface with alternating ridges and depressions. This is accomplished chiefly by means of slow migration of soil particles from soil surface in successive rains. In arid region, wind during the long dry season is an important factor for normal erosion.

2. Accelerated soil erosion

When the removal of soil does not keep harmony with the soil formation and it is much faster than the latter, it is called accelerated soil erosion.

AGENCIES CAUSING SOIL EROSION

Soil erosion is caused by the following two agencies :

(A) Climatic.

(B) Biotic.

(A) Climatic agencies causing erosion of soil

These are water and wind.

1. Water. Water is an important factor in soil erosion. Snow and melting snow also remove the top soil to considerable extents. Soil is directly affected by heavy rainfall, rapidly running water and by wave action.

Erosion caused by water may be of the following types :

(i) Sheet erosion. Uniform removal of a thin layer of soil from large area is called sheet erosion. It is affected by run-off effect of rain water.

(ii) Rill erosin. In this type of soil erosion, heavy rainfall and rapidly running water produce finger-shaped grooves or rills over the entire field (Fig. 19·1).

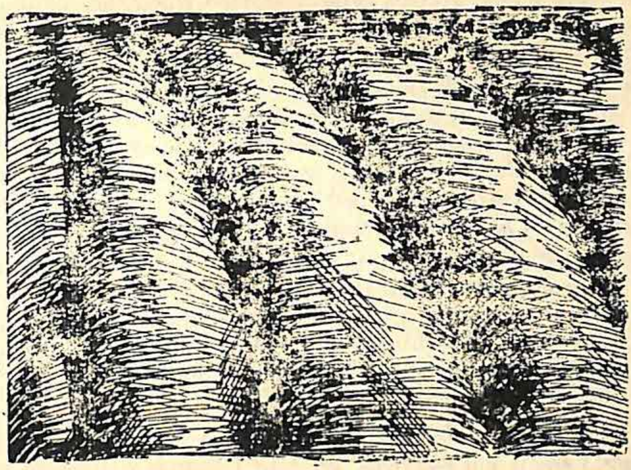


Fig. 19·1 Rill formation.

(iii) Gully erosion. It is more prominent type of erosion in which heavy rainfall, rapidly running water and transporting water may result in deeper cavities or grooves called gullies.

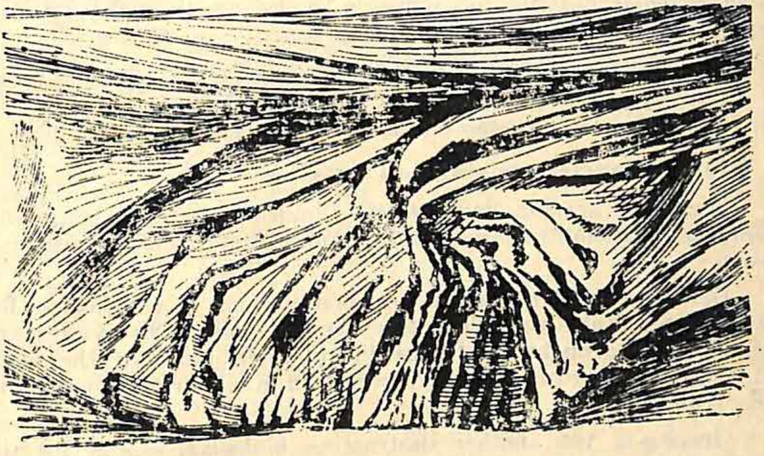


Fig. 19·2 Gullies,

Gullies may be 'V' shaped or 'U' shaped. Gullies cut the fields into small fragments and make them uncultivable (Fig. 19·2). Continuous flowing of water through gullies further deepens the grooves and may ultimately result in ravines. Ravines are 50 to 100 feet deep and with steep vertical sides.

(iv) Landslides or slip erosion. This type of soil erosion is caused by heavy rainfall and it occurs in slopy lands such as mountains and hills. In this type of erosion when the running water percolates through the crevices of rocks, great masses of soils and loose rocks lying on the steep slip downward.

(v) **Stream bank erosion**. On the banks of swollen rivers it is most active. In the rainy season when fast running water streams take turn in some other directions, they cut the soil and make caves in the banks. As a result of this, quite often large masses of soils become detached and washed away from the banks and are deposited at places in course of streams.

2. **Wind erosion**. Removal of soil by wind is called wind erosion. Stormy winds carry the soil with it to distant places and sometimes form sand-dunes. Wind currents usually remove the top soil which is fertile and full of humus and minerals. Wind causes the following three types of soil movements, *viz.*, (i) saltation; (ii) suspension; (iii) surface creep.

(i) **Saltation**. Under the influence of direct pressure of stormy wind small soil particles of 1 to 1·5 mm diameters move up from the soil surface, generally in vertical direction. Major part of wind carried soil is moved in a series of bounces, called saltation.

(ii) **Suspension**. In this, fine soil particles (diameter less than 1 mm) are suspended in air. These suspended particles are kicked up when particles of saltation strike on the soil. The soil particles are deposited at distant places.

(iii) **Surface Creep**. In this, there are larger particles ranging from 5 to 10 mm in diameter. Because they are too heavy to move in saltation, they creep on the surface of soil.

B. Biotic Agencies causing Soil Erosion

Excessive grazing, deforestation, undesirable forest biota, and mechanical particle by man are important factors which cause soil erosion.

Deforestation is the commonest factor which is responsible for soil erosion. Ruthless felling has exposed soils to direct effects of rain, snow and drought and has set in soil deterioration of the gully and sheet types over extensive areas in Kashmir (J.S. Singh and M.K. Wali, 1961).

Grazing is yet another destructive biological factor for the soil erosion. Cattle and sheep during the summer graze the forest vegetation and make the soil bare. Whyte (1957) while commenting on the problem of soil erosion of Kashmir, Himalayas, mentioned, "control of fluctuating grazing was made the responsibility of forest department in 1939 but this appears to have had little effect and the problem is as acute as ever".

Some other causes of Soil Erosion

1. Uneven distribution of rainfall.

2. **Shifting Cultivations**. Shifting cultivations are usually noted in the mountains which are geographically young and break

down into soil easily and the whole of the land is covered with a thick mantle of tropical forest vegetation. The removal of the forest or bush cover by felling and burning in shifting cultivation with resulting exposure of the bare soil to rains and sun, causes enormous soil losses especially on hill slopes. Both surface layer of the soil and large quantity of plant nutrients are quashed away under the influence of intense rainfall Shifting cultivation is a major problem in the hilly areas of Assam, Manipur, Tripura, Arunachal Pradesh, Nagaland, Orissa. It is reported that about 207,267 hectares in Assam, 46,963 hectares in Tripura, 21,862 hectares in Manipur and 308,502 hectares in Orissa, are under shifting cultivation. Shifting cultivation is practised sporadically in Andhra Pradesh, Madhya Pradesh, Maharashtra, Kerala, Karnataka and Tamil Nadu also. The process of shifting the area of cultivation is called by various names : *Jhum* or *Jum* in Assam, *podu, dahi or kamana* in Orissa, *penda* in Madhya Pradesh and so on. In English it is described as slash, burn or *Swidden* or simply as *Shifting cultivation*

3. Fields on steep slopes are cultivated and top soil is washed away by rains. The loss of soil is too much and the fields become uncultivable.

4. Forest fires are responsible for burning down forest trees on huge scale.

5. Faulty agricultural methods—Sometimes farmers do not care towards levelling and terracing of their upland fields. Rainfall washes away the top soil and erosion results.

6. Over-grazing by cattle causes removal of vegetational cover of the soil.

Factors affecting Soil Erosion

There are several factors which affect the erosion at a particular area. These factors are given below :

1. Nature of soil.
2. Distribution, nature and amount of precipitation.
3. General slope of the soil.
4. Vegetational cover.
5. Soil management.
6. Land use practices.

Consequences of Soil Erosion

There are several serious effects of soil erosion which are as follows :

1. Due to uprooting of trees shortage of timber and fuel results.
2. Loss of soil stability and fertility.
3. Shortage of fodder.
4. Destruction of land in plains.

5. Formation of sand dunes.

6. Greater frequency of floods and threat to communication channels.

7. Silting of river bed, lakes and dams.

8. Higher temperature and lower rainfall.

SOIL CONSERVATION

The main aims of soil conservations are as follows :

(1) To protect the soil from erosion.

(2) To maintain the productive capacity of the soil.

Soil erosion is a natural phenomenon by which soil is removed from rocks. Accelerated erosion due to misuse of resources of land, water and soil is today one of the most difficult and pressing problems before man. Both engineering and biological methods have been used to check the soil erosion but it is still without a plausible check. Vast tracts of fertile land are rendered useless on account of industrialisation and development. Erosion has posed a serious challenge in the United States, South and North Africa, Japan, Mesopotamia, North China, India, Pakistan and in a number of other countries. In India, we are aware of advancing deserts of Rajasthan and erosional losses, floods etc., in other parts of the country. The problem has received the attention of forest ecologists, soil scientists and engineers only recently.

Practical methods of soil conservation are broadly grouped as follows :

(A) Biological measures,

(B) Mechanical or Engineering methods.

A. Biological Measures

The following are the biological methods which are helpful in checking the soil erosion :

1. Agronomic practices ;
2. Agrostological methods ;
3. Dry farming practices.

1. Agronomic Practices. The important agricultural practices which contribute to the conservation and productivity of cultivated lands are referred to as conservational farmings or advanced agronomical methods. These are listed as under :

(*i*) Contour farming

(*ii*) Tillage and keeping the land fallow

(*iii*) Crop rotation, sowing of leguminous crops, and mixed cropping

(*iv*) Mulching

(*v*) Strip cropping

(*i*) **Contour Farming.** It is practised in the hilly regions or on the slopes. In such areas, rain water is absorbed in the very little amount because of its quick downward movement on the slopes. If these slopy areas are ploughed up and down the slope, the heavy rainfall may cause gully development. Taking into consideration this defect, the slopy areas are ploughed and seeded against the slope, *i.e.*, in circular furrows around the slopes. This process is termed as *contour farming*. The contours (circular or peripheral furrows) catch the downwardly moving water until it is absorbed in the soil. The ridges reduce the flow of water. The circular rows of plants across the slopes check the soil erosion. Thus contour farming reduces run off, saves more water for crops, reduces soil erosion and increases the yield of crops (Fig. 19·3).

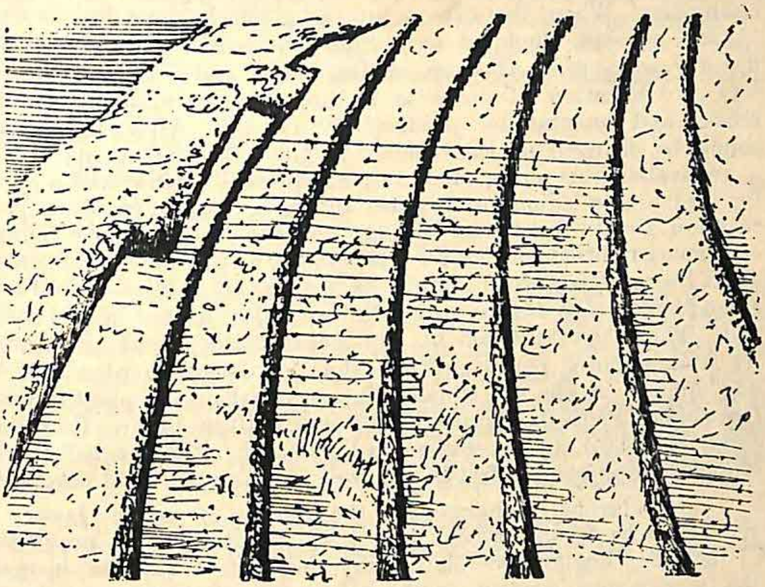


Fig. 19·3—Contour strip cropping for controlling soil erosion and strip cropping for controlling soil and moisture losses on uniform slopes.

(*ii*) **Tillage Operation and Keeping the Land Fallow.** There are several diverse opinions as to whether deep ploughing gives good result or shallow ploughing. A number of researches support the view that in dry areas, shallow ploughing gives comparatively good crop yields. Shallow ploughing removes the weeds and enables the soil to absorb water. Deep ploughing often leads to soil erosion but in the areas where rainfall is sufficiently high, deep ploughing (up to 15—30 cm deep) are effective in removing weeds and increasing crops yields.

If the land is left uncultivated and sheep, goats and other cattle are allowed to graze and sit over it for some time, the soil becomes fertile. Though this practice is useful yet it is not possible in the countries like India where exists severe problem of cereals because of thick human population.

(*iii*) **Crop Rotation, Sowing of Legumes, and mixed cropping**. When the same crop is grown in the field every year, the soil becomes depleted in certain minerals. The soil loses its fertility even after the use of fertilizers and ultimately erosion sets in. Rotation of crops is an important method for checking erosion and maintaining productivity of soil. After 2 years crop should be changed in the fields. A good rotation should include a cultivated row crop, densely planted small grasses and a spreading legume or a legume and grass mixture. Selection of crops for rotation should be made taking into consideration the climate, economic condition, soil types, soil texture, slopes, nature of erosion, etc. Deep-rooted crops should be rotated by shallow-rooted crops. Deep rooted crops absorb nutrients from the deeper strata of the soil. Thus, the minerals of top soil remain stored for future use by shallow rooted plants. When the deep rooted crops die, they add humus in the soil which is future storehouse of plant nutrients. Growing of *Phaseolus mungo* (Mung in Hindi) in Bihar, *P. radiatus* (urad in Hindi), and *P. mungo* in U.P. in kharif season before wheat cropping improves soil fertility as well as yields of cereal crops.

In Vidarbha (Maharashtra), the rotation of cotton, jowar, and groundnut has been proved useful in maintaining the productivity of the soil. Leguminous plants play very active part in increasing the nitrogenous contents in the soil because of the fact that bacteria inhabiting their root nodules fix the free nitrogen of atmosphere into nitrogenous compounds such as nitrates, nitrites ammonium salts, amino acids and proteins. The nitrogenous compounds return to the soil by way of death and decay of underground nodulated roots of these legumes. Thus, growing of leguminous plants is one of the important methods for maintaining soil fertility.

The rotation of crop serves the following purposes :

(*a*) Enriches the soil.

(*b*) Improves the soil texture.

(*c*) Improves water holding capacity of the soil.

(*d*) Improves crop production.

(*e*) Controls the recurrence of weeds and diseases.

Mixed cropping is another important method for increasing productivity of the soil. In this practice, one main crop and one or two subsidiary crops are grown together on the same land, as for example, growing of Arhar, Urad, Til along with millet. This practice checks the soil erosion and avoids the risk of crop failure. If one crop fails due to diseases or any other factor, the other remains ensured.

(*iv*) **Mulching**. It means covering the soil surface by straw leaves or grasses. Mulches of different kinds check soil erosion, increase soil fertility and also minimise moisture evaporation from the top soils. Various types of surface tillers and crop residues are helpful in obstructing the movement of soil particles.

(*v*) **Strip cropping**. It is an important method which employs all the advanced cultivation practices such as contour farming, proper tillage, crop rotation, mulching, cover cropping etc. Strip cropping is very effective and practical means for controlling soil erosion. It is of the following types :

(*a*) Contour strip cropping

(*b*) Field strip cropping

(*c*) Wind strip cropping

(*d*) Permanent or temporary buffer strip cropping.

(*a*) *Contour Strip Cropping*. It is a special type of contour farming in which soil exposing crops, are grown on the strips across the slope on the level or contour and in the following season soil protecting crops are sown on the strips on which soil exposing crops were grown in the previous season and again in place of these soil protecting crops some soil exposing crops are sown. This practice is useful because it checks the fast flow of run-off water, increases the infiltration of water in the soil and prevents soil erosion.

(*b*) *Field Strip Cropping*. It is a farming in more or less parallel strips across fairly uniform slopes but not on the exact contour.

(*c*) *Wind Strip Cropping*. In this method tall growing plants (*e.g.*, Bajra, Jowar, etc.) alternating with the short growing crops such, as 'Arhar', 'Urad' are sown in long straight strips right across the direction of wind regardless of contour.

(*d*) *Permanent or temporary buffer strip cropping*. This is a special type of contour strip cropping in which care is taken to check the soil erosion. In this, crop rotation practice is not applied and on the strip perennial legumes and grasses are planted on permanent or temporary basis.

(2) **Agrostological Methods**. The following are the important agrostological practices that check soil erosion :

(*i*) Cultivation of grassses (ley farming).

(*ii*) Retiring the land.

(*iii*) Afforestation and Reforestation.

(*iv*) Checking of overgrazing.

(i) Cultivation of grasses (Ley farming). This method consists in growing grasses in rotation with agricultural crops. This practice improves the fertility of soil and helps in binding of the soil, thus preventing the soil erosion. This practice is recommended for Nilgiri and similar places which are subjected to very severe soil erosion.

(ii) Retiring the Land. Areas subjected to heavy soil erosion should necessarily be put under thick cover of grasses, Under favourable climatic conditions grazing should also be allowed for short periods. Researches conducted at Solapur in Maharashtra have shown that grasses have good soil binding capacity. In Nilgiri hills Tamil Nadu doobgrass (*Cynodon dactylon*), *Dectylis glomerata*, *Eragrostic amabitis* and *E. cerbula* are proved most effective in binding the soil and in stabilizing the reserves of the bench terrace and sodding water channels.

(iii) **Afforestation and Reforestation.** *Afforestation* means growing forests at places where there were no forests before owing to lack of seed trees or due to adverse factors such as unstable soil, aridity or swampiness. *Reforestation* means replanting of forests at places where they have been destroyed by uncontrolled forest fires, excessive felling and lopping. Plantation of trees in short blocks is known as a *wind break* and extensive plantation of trees is called *shelter belts*. Wind breaks and shelter belts type of plantations are being done in some regions of Uttar Pradesh where desert is encroaching. The plantation is usually done in two or three belts. Small sized plants are planted on windward side and tall trees on leeward side. These reduce the wind velocity considerably and also check the transport of lifted sand and soil particles. Afforestation is the best means to check the soil erosion. Lutz and Chandler (1946) cited the following points in support of the vegetational check of erosion :

(*a*) Infiltration of water is favoured due to high porosity of soil under vegetation. Percolation of water helps in preserving the soil moisture which accelerates further growth of the vegetation.

(*b*) Surface accumulation of organic matter increases the water holding capacity of soil.

(*c*) Root systems of the vegetation hold the soil mechanically and provide stability of the underground soil.

(*d*) It gives protection to soil against wind. The forest vegetation shields the soil from direct effects of drought, snow and rain.

Destruction of vegetational cover usually results in accelerated erosion, flooding and silting. The worst past victims of soil erosion tell the story of drastic deforestation (destruction of forests). In our country deforestation has been recognised as the most potent and powerful cause of soil erosion and efforts are being made to check it.

State forest departments in India have already undertaken this practice, although in very restricted areas, and have met with good success. Forest departments in Baramulla, Gulmarg, and Banihal in Kashmir afford good examples. In Baramulla region, mixed planting of *Pinus*, *Cedrus* and other species have been done. The plants are thriving well and have checked erosional losses of soil to a great degree. In the area where plantations have not been made the soil is actively eroding. Another example is afforded by Sankaracharya Hills in the vicinity of Srinagar which was heavily eroded in the past. It has now been improved by afforestation.

Forest department took up the planting of conifer species like *Pinus wallichiana*, *P. roxburghii*, *P. sylvestris*, *P insignis*, *P. gerardiana*, *Cupressus arizonica*, *C. Sempervirens*, *Juniperous* species, *Cedrus deodara*, and broad leaved species, like *Aesculus indica*, *Fraxinus*, *Juglans regia*. These plants check erosion to some extent.

The efforts are being made to check the spread of Rajasthan desert towards Uttar Pradesh and the plantation is being done in that region in two or three belts. Small-sized plants are planted on the windward side and tall trees on the leeward side. On the windward side *Leptadenia spartium*, *Cenchrus ciliaris*, *Balanites roxburghii*, *Calligonum polygonoides*, *Sachharum munja*, *Kochia indica*, etc. are commonly planted and on lee ward side *Acacia senegal*, *A. leucophloea*, *Ricinus communis*, *Prosopis spicigera*, *P. juliflora*, *Parkinsonia*, etc., are being grown.

The problem of afforestation is the selection of suitable species for a given area. This can be accomplished by dividing the whole area into different catchment zones according to climate, soil and biota. Suitable species for each zone should be selected from those already growing there. Knowledge of successional trends of the vegetation will be of great help in afforestation practices. Lutz and Chandler (1946) have stated that climax vegetation in any region is most effective agent to prevent accelerated erosion. Afforestation also checks the erosion of unsuitable rocks probably by checking the leakage of water (Puri 1951).

Along with afforestation and reforestation, forest management practices should also be strictly enforced, which require

(a) Control on forest fires

(b) Extension of forest areas

(c) Checking extensive felling and lopping

(d) Restricted grazing in forest areas

(e) Formation of reserve forests.

(iv) **Checking of overgrazing**. Since grazing in all the areas subjected to soil erosion cannot be completely stopped, a system of restricted and rotational grazing may be helpful in checking soil erosion to some extent. The area open to grazing for sometimes should be closed for the following years to facilitate regeneration of forest and to maintain thick ground vegetation.

3. **Dry Farming Practices**. Dry farming is useful in thos areas where rainfall is very low, uncertain and uneven in distribution. In such areas maximum conservation of water in the soil and reduc tion of soil erosion are the two main problems.

The improved dry farming practice developed as a result of researches carried out in India is an integrated rational system of cultivation of purely rainfed and drought enduring crops in dry areas. This practice consists in bunding, both contour and compartmental, and all other advanced agricultural practices to conserve maximum amount of rain water in the soil so as to make it available for crops during their growth period. In this, usually early maturing crop varieties are selected for cultivation. Important dry farming regions of India are :

(1) Punjab,

(2) Rajasthan,

(3) Southwest part of U.P., Northwest part of M.P.,

(4) Some parts of peninsular India including dry tracts of Bombay, Mysore, Andhra Pradesh and Tamil Nadu.

Dry farming methods and selection of crops vary in different regions as per requirement of local conditions.

B. Mechanical Methods

It is only in recent years soil erosion problems have received attention of engineers. The mechanical practices of soil conservation include various engineering techniques and structures which are adapted to supplement the biological methods when the latter alone are not sufficiently effective. These practices aim at the following objectives :

1. Reduce the velocity of run-off water to retain it for long period so as to allow maximum water to be absorbed and held in the soil.

2. To divide a long slope into several small parts so as to reduce the velocity of run-off water to the minimum, and

3. Protection against erosion by wind and water.

Mechanical methods for soil conservation are:

(*i*) Basin leaching
(*ii*) Pan breaking
(*iii*) Sub-soiling
(*iv*) Contour terracing
(*v*) Contour trenching
(*vi*) Terrace outlets
(*vii*) Gully control
(*viii*) Digging of ponds and reservoirs
(*ix*) Stream bank protection.

(i) **Basin leaching.** In this method, a number of small basins (water reservoirs) are made along the contour by means of an implement called basin blister. Basins collect and retain rain water for long period and also catch and stabilize downwardly moving soils of the slopes.

(ii) **Pan Breaking.** In some areas, soils become impervious to water and are less productive because of formation of hard sheet of clay pan a few feet below the surface. Such areas can be made productive and water permeable by breaking hard clay pans by means of pan breaker on contour at a distance of about 5 feet. By pan breaking, drainage and percolation of rain water is improved and soil is saved from residual run-off and erosion.

(iii) **Sub-soiling**. In this method hard subsoil is broken deeply by means of an implement called sub-soiler without involving the conversion of soil. This process promotes absorption of rain water in the soil and makes the soil more loose and fit so as to allow luxuriant growth of vegetation.

(iv) **Contour Terracing**. Sometimes drainage channels or properly spaced ridges or soil mounds are formed along the contour to check soil erosion. These are called terraces. Terracing may be of the following four types :

(*a*) *Channel Terracing*. This is concerned with making of wide but shallow channels on contours at suitable distance. In this process, the excavated soil is deposited along the lower edge of channel in the form of low ridge.

(*b*) *Narrow based Ridge Terracing*. This process is commonly called bunding. In this a number of narrow based ridges or bunds are constructed at distance of 1 m to 2m across the slope along the contour.

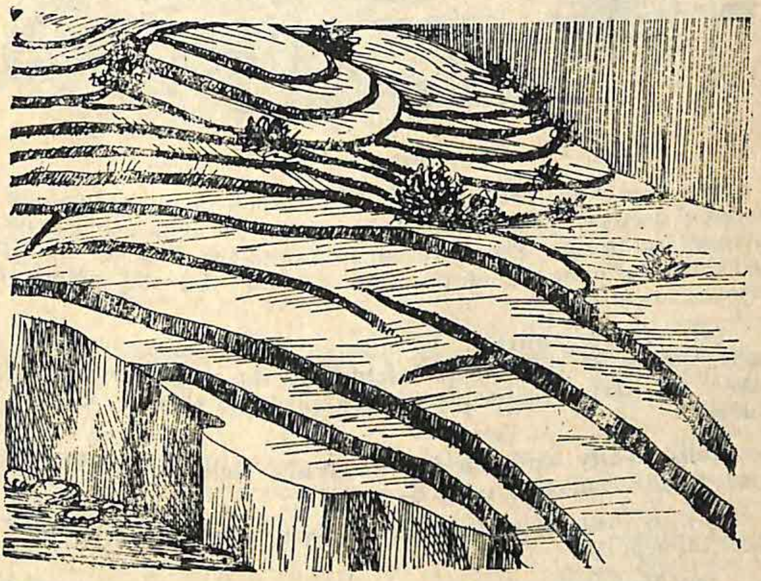


Fig. 19·4 —Bench terraces on a steep slope.

(*c*) *Broad-based Ridge Terracing*. In this, wide but low bunds are made on contour by excavating soils from both the sides of ridge.

(*d*) *Bench terracing*. This method involves making of wide steplike platforms, the so called bench terraces, having suitable drops along contours (Fig. 19.4 Along the outer edges of bench terraces bunds of about one foot height are raised to check the downward flow of rain water and also soil erosion. The vertical drops may vary from 1m to 2m. Bench terracing is very costly process and so it should be applied in the area of land scarcity for growing money crops.

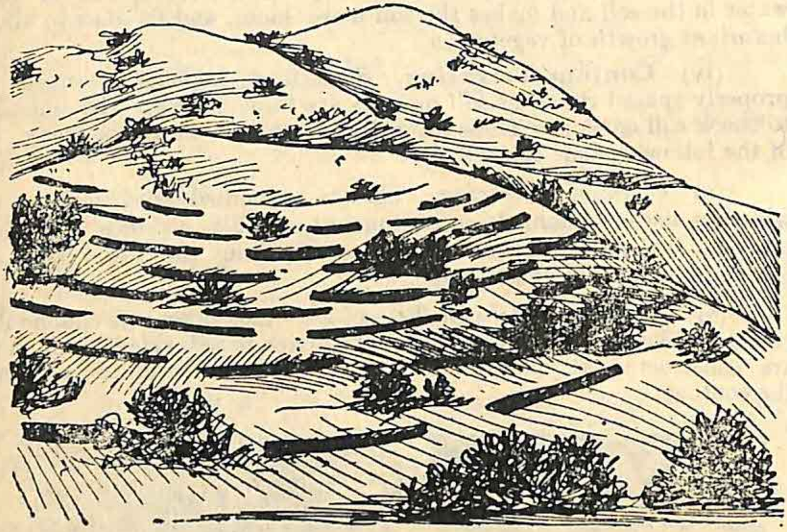


Fig. 19·5 —Contour trenching on a sloping land.

(v) **Contour Trenching.** This method involves making of a series of deep pits (2′ × 1′) or trenches across the slope at convenient distance (Fig. **19.5**). The soil excavated from the trenches are deposited along the lower edge in the form of bund. On the ridges tree seeds are sown.

(vi) **Terrace outlet.** In order to reduce soil erosion and to remove excess of rain water safely from the contour terraces pipe outlets are used or channels are made which are thickly covered by grasses.

(vii) **Gully and Ravine control**. Gully formation can be checked by the following methods :

(*a*) By making perimeter bunds around gullies to check flow of water through it.

(*b*) By growing suitable soil-binding vegetation on the gullies to check soil erosion.

(*c*) Diversion trenches should be made around gullies.

(vii) **Ponds and reservoirs**. Small ponds and water reservoirs or dams (Fig. **19.6** should also be made at suitable places for irrigation and some other purposes. Various types of dams have been devised to arrest and plug gullies and thus to check soil erosion.

These dams may be (a) brush dams (b) earth dams, (c) concrete dams or (d) woven wire dams.

9. **Stream Bank Protection**. Banks of ravines and rivers with high vertical drops are subjected to heavy soil erosion. The bank erosions can be checked by making the drop slopy and by growing vegetation on the slopes or by constructing stone or concrete pitching.

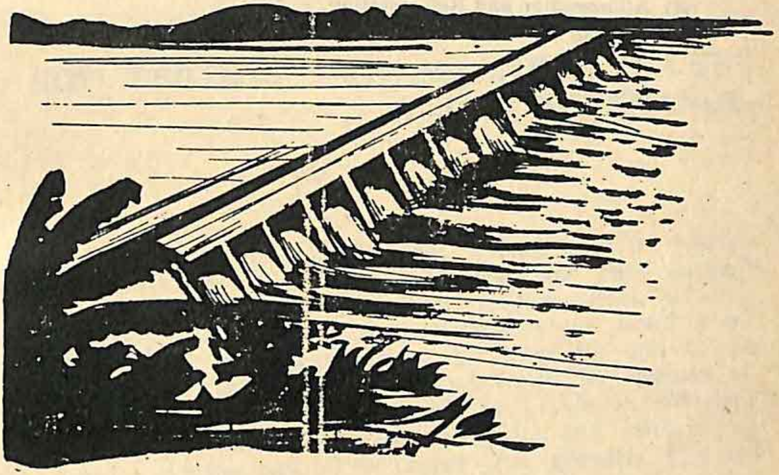


Fig. 19·6 A—dam.

The problem is very complicated and is receiving attention of scientists and engineers. The erosion of Siwaliks has been studied by Glover and Hamilton (1935) and Gorrie (1951) and various methods have been suggested for soil conservation. Recently Puri (1949, 1954) analysed the problems from different angles and suggested that soil should be kept under tree vegetation in order to check erosional losses and landslides. The Central Arid Zone Research Institute in collaboration with UNESCO is attempting to check erosional losses in Rajasthan. The Indian Council of Agricultural Research (ICAR), especially the Waste Land Reclamation Committee is giving attention to the problem in collaboration with some State forest and agriculture departments. Central Soil Conservation Board has established 9 research centres, one each at Dehradun, Kota, Ootacamund, Bellary, Vasad, Agra, Chandigarh, Jodhpur and Chhatra to organise, co-ordinate and initiate researche on soil conservation, to meet the paucity of trained personnel for manning soil conservation schemes and to assist State and river valley projects technically.

QUESTIONS

1. Comment upon the following statemants :

(*i*) Presence of micro-organisms in soils is ha.mful to soil fertility.

(*ii*) Acid soils are better for plant growth than alkali soils.

(*iii*) Base exchange causes soil erosion.

2. Define soil erosion. Give an account of various factors causing erosion of soil.
3. What are the aims of soil conservation ? Discuss in brief the various biological and mechanical methods of soil conservation.
4. Write short notes on :
   (*i*) Crop rotation.
   (*ii*) Afforestation and Reforestation.
   (*iii*) Contour farming.

20

SOIL FERTILITY—ITS MEANING, CAUSES AND MAINTENANCE

The soil is a natural medium for plant growth and it supplies nutrients for plants. Some soils are productive and they support luxuriant growth of plants with very little human effort, whereas others may be unproductive which support almost no useful plant life regardless of every human effort. In order for soil to be productive, it must be (*i*) easily tillable and fertile, (*ii*) contain all essential elements in forms readily available to plants in sufficient amount, and (*iii*) physically good to support plants and contain just the right amount of water, and air for proper root growth. The soil must supply these essentials every day in the life of the plant.

Soil fertility and soil productivity appear to be synonymous but in soil science these two terms bear different meanings. Soil fertility may be defined as the ability of soil to provide all essential plant nutrients in available form and in a suitable balance whereas soil productivity is the resultant of several factors such as soil fertility, good soil management practices, availability of water supply and suitable climate. A soil can be highly fertile, *i.e.*, it has ready supply of nutrients in available form, yet it may not be highly productive. **Water-logged** soils may be highly fertile but may not produce good crop because of the unfavourable physical conditions. A fertile soil may be highly saline or alkaline which may not be good for agriculture. Sandy soil may be poor in fertility but with the use of fertilizers and water it may be made productive. Soil fertility thus denotes the status of plant nutrients in the soil whereas the soil productivity is the resultant of various factors influencing crop production.

In fact there is no standard for either fertility or productivity because both depend upon the crops to be grown. Soil that is productive for potatoes may not necessarily be productive for certain other crops.

PLANT NUTRIENTS

Of the 90 or so chemical elements forming the earth's crust, 16 are known to be essential for plant growth and reproduction. Seven elements needed in quantity (*macro nutrients*) are : hydrogen. oxygen, nitrogen and carbon from air and water and phosphorus, potassium and calcium from mineral particles in the soil. The other 9 elements needed only in small amount (micronutrients) are : magnesium, sulphur, boron, copper, iron manganese, zinc, molybdenum and chlorine.

Jacob and Uexkull have listed cobalt and sodium as essential elements for plant growth. With the exception of hydrogen, carbon, and oxygen all other inorganic plant requirements are obtained directly or indirectly from the soil minerals, hence these elements are called mineral nutrients. Strictly speaking nitrogen is not a mineral element but it has been included in the list because it can also be obtained by plants from soil.

The mineral elements are taken by plants from soils mostly in the form of ions. Plants obtain nutrients from the following four devices :

(*i*) from the soil solutions through roots,

(*ii*) from exchangeable ions on the surface of clay and humus particles through roots,

(*iii*) from readily decomposable minerals, and

(*iv*) through the leaves.

The essentiality of an element is proved by the following criteria :

(*a*) The element may be considered essential if its exclusion from the nutrient medium inhibits or drastically reduces the growth and reproduction of plant.

(*b*) Acute deficiency of the element produces certain well defined disease symptoms which are not produced by the deficiency of any other element.

(*c*) Deficiency disease symptoms will disappear if the particular element is supplied, before the living system has been damaged beyond repairs.

The capacity of soil to supply the essential elements is a fundamental edaphological problem. In natural habitat the plant matter is returned to ground through decay and unless there is extensive leaching and percolation the inorganic nutrients become available again for new growth. Many farm crops are removed from ground *in toto* and the supply of essential elements thereby becomes depleted. To replace these elements taken away from ground by crops, manures or fertilizers are added. Unless it is done the crop will suffer from deficiencies in the essential elements. Deficiencies become reflected in the growth of plants in several ways ; some may cause a reduction in yield as a result of poor plant growth and some may delay maturation of crop, a function that may be very vital to crop yield in the places where the growing season is short. The symptoms of mineral deficiencies may be dwrafed, spotted distorted, curled or wilted leaves or rotting of the centre of fruits. Different mineral nutrients have certain specific deficiency symptom. The physiological roles of various mineral elements in the life of plants and deficiency symptoms caused by them can be found in any plant physiology book.

SOIL FERTILITY FACTORS

Several factors are known to govern the fertility of soil. Some of the important factors are discussed below :

1. As a result of cropping, a large amount of organic matter and soil minerals are removed and if the normal cycling of mineral elements is retarded, loss in soil fertility results.

2. Besides cropping, soil erosion also causes tremendous loss of plant nutrients from the top soil.

3. Conversion of organic form of nitrogen locked in humus into ammonia gas and nitrogen gas and leaching out of soluble nitrates and nitrites from surface soil greatly affect the fertility status of soil.

4. Abundance of certain nutrient elements in soluble form may be as unsatisfactory as ground that has deficiency and even the elements, say alkalies, essential for plant growth may be toxic if present in excess. Flowering plants do not grow in the soil containing more than 6 per cent NaCl and other salts. The elements are not equally toxic and the various species of plants differ in their susceptibility to different elements.

5. **Toxic chemicals and Pesticides in soil**. Several agricultural chemical being used for controlling various diseases and insect pests are highly toxic and their application adversely affects the soil microflora and fauna. Prolonged persistence of these pesticides in soil is bound to lower the soil fertility both directly and indirectly.

6. **Soil Reaction**. The soils may be alkaline or neutral or acidic in their reaction. Some plants find acid soil unsuitable for growth and other plants find alkaline ground unfavourable pH value of soil solution determines the availability of certain plant nutrients and thus it has a bearing in soil fertility problem. Increase in the acidity of the soil makes mineral salts more soluble in soil solution and thus salts may become available in concentrations that may be highly toxic or may damage plants growing in such soils. Janick *et al.* (1969) have demonstrated that high concentration of both iron and aluminium may damage plants growing in acid soils.

MAINTENANCE OF SOIL FERTILITY

Soil fertility is the most important asset of a nation. Maintenance of soil fertility is an important aspect of agriculture. The soil fertility problem has been studied in many countries and scientists have brought to light several facts concerning soil fertility and its maintenance.

Soil fertility is of two types ;

(*a*) **Permanent fertility**. It is derived from the soil itself. It can be improved, maintained or corrected by soil management practices.

(*b*) **Temporary fertility**. It is acquired by suitable soil management but the response of build up soil fertility is highly dependent on the degree of permanent fertility which is already there.

Several methods are known for controlling the loss of soil fertility. Here only the important methods are discussed.

1. Application of organic manures and chemical fertilizers.

A. Organic manures

The organic content of the soil which is a good source of plant nutrients contributes most to the fertility of the soil. Organic manures improve soil fertility in the following ways :

(*i*) They modify the physical properties (as increase of granulation) of the soil and increase permeability and moisture holding capacity of soil.

(*ii*) They provide food for soil microbes and thus enhance microbial activities.

(*iii*) Decomposition products of organic manures help to bring mineral constituents of soil into solution.

(*iv*) Improve physico-chemical properties of soil such as cation exchange and buffering action.

Organic manures are of several kinds some of which are discussed below :

(*i*) **Farmyard manures**. Solid and liquid excreta as dung and urine of all farm animals are termed farmyard manures. They are ready made manures and contain nitrogen, phosphorus and potassium. The farmyard manures of different animals vary greatly in their composition but they are good for all types of soils and all the crops. Farmyard manure when collected in field in exposed condition for several months shows considerable loss of fertilizing value as upon decomposition a considerable amount of ammonia is lost by volatilization. Therefore it is important to keep manure protected from weather and manure preparation should be carried out in trenches of about a metre depth. When the trenches are filled the top surface is covered with a cowdung-earth slurry. In about 3 months the manure is ready for use.

(*ii*) **Compost**. Compost manure can be prepared from a variety of refuse materials such as straw, sugarcane refuse, rice hulls, forest, litter, weeds, leaves, kitchen wastes. It is prepared in pits usually 6—8 m long, 1½ to 2 m wide and one metre deep.

In the pits, 30 cm thick layer of plant residues moistened with cowdung, urine and water is formed and then a second layer of about 30 cm thickness of mixed refuse is spread over it and moistened with slurry. The operation is repeated until the heap rises to a height of about 50 cm above ground level. The top is then covered with a thin layer of moist earth. After three months of decomposition the material is well mixed and again covered. After a couple of months the manure is ready for use. There are two types of composts :

(*a*) *Farmyard compost* which is obtained from animal excreta and plant residues.

(*b*) *Town compost* which is obtained by decomposition of kitchen wastes of towns and cities.

Compost manures are rich in all plant nutrients.

(*iii*) **Green manures**. Green manuring is the practice of growing, **ploughing and mixing** of green crops with soil to improve soil fertility and productivity. Its effects on soils are similar to those of farmyard manures. It is cheap and best method to increase soil fertility as it can supplement farmyard and other organic manures without involving much cost. Green manures add nitrogen and organic matter to the soil for the improvement of crop yield. Through green manuring mobilization of minerals, reduction of organic nutrient losses due to erosion, leaching and percolation improvement in physical, chemical and biological activities of the soil can be achieved. Green manuring also improves soil aeration and drainage conditions. For green manuring both leguminous and non-leguminous crops are used. In India, leguminous crops such as sannhemp (**sanai**), Dhaincha, Berseem, Clover, *Phaseolus*, Cowpea, are generally used for green manuring.

(*iv*) **Sawdust**. Sawdust can be used as bedding material to conserve animal urine or for making compost. It is a low fertilizing material but it is definitely richer than wheat straw in calcium.

(*v*) **Sewage**. In modern system of sanitation, water is used for removal of human excreta and other wastes. Sewage consists of two components :

(*a*) the solid part, called *sludge* and (*b*) the liquid part, called *effluent* or *sewage water* Sewage is quite rich in several plant nutrients and can be used for fertilizing the crop by irrigating the soil directly with sewage water but there is a danger for the spread of several human diseases.

B. Chemical fertilizers

Of the elements known to be essential for plant growth, nitrogen (N), phosphorus (P) and potassium (K) are required by plants in pretty large amounts, and are therefore designated *major* or *primary nutrients* while calcium, magnesium and sulphur are secondary nutrients. For acid soils, use of Ca and Mg is necessary.

Seven elements iron, manganese, boron, molybdenum, copper, zinc and chlorine are required in trace amount and hence called micronutrients. Under continuous cultivation our soils are losing organic matter and mineral nutrients faster than they can be replaced. Regular loss of nutrients from the soil results in compact soil, shallow roots, increased drought, claddy and poorly productive soil. So, for the maintenance of soil fertility quick replacement of the organic matter and mineral nutrients removed from the soil is necessary.

Nitrogen (N), phosphorus (P) and potassium (K), the primary plant nutrients are commonly applied to soils in the form of commercial fertilizers and hence they are often referred to as *fertilizer elements*.

Chemical fertilizers are classified into the following three groups on the basis of materials supplied : (*i*) Nitrogenous fertilizers, (*ii*) Phosphorus fertilizers, and (*iii*) Potassium fertilizers. Classification is not so simple as this grouping would imply, however, several fertilizer materials carrying two of these elements as for example, potassium nitrate and ammonium phosphate.

(*i*) **Nitrogenous fertilizers**. Crops usually take nitrogen from the soil in the form of nitrate $(NO_3)^-$ and ammoniate $(NH_4)^+$. Nitrogen fertilizers may be divided for convenience into two groups : (*a*) Organic nitrogen fertilizers, and (*b*) Inorganic nitrogen fertilizers.

(*a*) **Organic nitrogen fertilizers**. Organic materials such as cottonseed meal, guano and fish tankage are nitrogen carriers but because they supply less than 2% of total nitrogen added on commercial fertilizers, their use is costly and hence they are not used extensively. Nitrogen of organic fertilizers is released slowly by microbial action. They are used as special fertilizers for gardens, lawns and potted plants.

(*b*) **Inorganic nitrogen fertilizers**. Several inorganic chemicals are used to supply nitrogen to plants. The most important of these are presented in the table on page 303.

(*ii*) **Phosphorus fertilizers**. Phosphorus has rightly been called "master key to agriculture as low crop production is due to more often to lack of phosphate than to the deficiency of any other element except nitrogen. In phosphorus fertilizers this element is present in the form of phosphate or superphosphate salts and it is available to the plants when it is combined with organic matter or with calcium and magnesium. Phosphorus is also found in combination with iron and aluminium and is present in certain rock minerals as apatite. Plants take up phosphorus chiefly as phosphate $(PO_4)^{--}$, HPO_4^{--} and $H_2PO_4^-$ ions and availability of these ions depends chiefly upon the acidity of the ground. They become nearly insoluble in strongly acid or strongly alkaline soil. Release of phosphorus from phosphate rocks is slow. The breakdown of phosphate fertilizers produces phosphoric acid (P_2O_5) in soluble form that is absorbed by plants. Use of phosphate fertilizers on

Fertilizer	Composition	Source	Nitrogen %
1. Ammonium sulphate	$(NH_4)_2SO_4$	Byproduct from coke and gas and also as synthetic	26·6
2. Ammonium nitrate	NH_4NO_3	Synthetic	33
3. Ammonium chloride	NH_4Cl	Synthetic	25
4. Ammonia liquor	Dilute NH_4OH	Synthetic	20—25
5. Ammonium phosphate	$NH_4H_2PO_4$	Synthetic	11% N and 48% P_2O_5
6. Diammonium phosphate	$(NH_4)_2HPO_4$	Synthetic	21% N and 53% P_2O_5
7. Sodium nitrate	$NaNO_3$	Chile saltpetre and synthetic	16
8. Calcium ammonium nitrate	NH_4NO_3 and Dolomite	Synthetic	20·5
9. Calcium cyanamide	$CaCN_2$	Synthetic	21
10. Calcium nitrate	$Ca(NO_3)_2$	Synthetic	15
11. Urea	$CO(NH_2)_2$	Synthetic	45

alkaline soils is not suitable. Phosphorus fertilizers are classified into (*i*) water soluble. (*ii*) citrate soluble, and (*iii*) insoluble. When the term P_2O_5 is used, it means water soluble plus citrate soluble P_2O_5. Following are the important phosphate fertilizers being used in all parts of the world including tropical Asia :

Fertilizer	*Chemical composition*	*P_2O_5 available percentage*
a. **Fertilizers containing water soluble phosphorus**		
(*i*) Super phosphate (ordinary grade)	$Ca(H_2PO_4)_2$ and $CaHPO_4$	16—20
(*ii*) Superphosphate (concentrated)	,,	40—45
(*iii*) Ammonium phosphate	$NH_4H_2PO_4$	48(11%N)
(*iv*) Diammonium phosphate	$(NH_4)_2HPO_4$	46—53 (4%N)
b. **Citrate soluble phosphorus fertilizers** :		
(*i*) Dicalcium phosphate		35—40
(*ii*) Basic slag (Indian)	$(CaO)_5P_2O_5.SiO_2$	3—5
c. **Insoluble phosphorus fertilizers** :		
(*i*) Rock phosphate	Fluor and chloraphatite	20—30
(*ii*) Bone Meal	$Ca_3(PO_4)_2$	18—20

Superphosphate. It is water soluble fertilizer. It does not affect the soil adversely. It contains monocalcium phosphate. dicalcium phosphate and tricalcium phosphate, gypsum, silica, iron, aluminium sulphate and calcium fluoride and water.

Ammonium phosphate. It is a fertilizer containing both nitrogen and phosphorus. It is rich in phosphoric acid content but comparatively low in nitrogen content.

Ammonium superphosphate ($NH_4H_2PO_4$. $Ca(PO_4)_2$ $(NH_4)_2SO_4$. It is cheapest fertilizer and is a mixture of nitrogen and phosphorus fertilizers. It contains nitrogen 3 to 4 per cent and phosphorus pentaoxide (P_2O_5) 16 to 18%.

Nitrophosphate. It is highly hygroscopic. It contains nitrogen 13—18 per cent and phosphorus 20 per cent. It is suitable for acid soils.

Bone meal. It is derived from bone. Bone ash and bone char are the bone products. It is suitable for acidic soils.

Basic slag. Basica slog, a byproduct in the manufacture of steel, is one of the cheapest sources of phosphorus. It is a double compound of silicate and phosphate of lime. It is dark brown in colour and alkaline in reaction.

Rock phosphate. It occurs in natural deposits. It is light grey in colour. It is a very cheap fertilizer suitable for acid soils.

(*iii*) **Potassium fertilizers**. These fertilizers are soluble in water which means that potassium is readily available to plants. Total potassium of potassium fertilizers is usually expressed in terms of water soluble potassium (K) or potash (K_2O). Soils of arid and semiarid areas are generally well supplied with potassium. Acid areas usually need potassium fertilizers more than neutral or alkaline soils because acid soils develop in the areas of high rainfall that leaches out available potassium. All potassium fertilizers are physiologically neutral in reaction. Following are some common potassium fertilizers.

(*i*) **Potassium chloride**. It is also called muriate of potash. It contains 48—62% K_2O. It is cheap and neutral in reaction.

(*ii*) **Potassium sulphate**. It contains about 50% potash (K_2O). It is expensive fertilizer.

(*ii*) **Kainite**. It is natural potassium mineral which contains 14—20% potassium. It is suitable for alkaline soils.

(*iv*) **Wood ashes**. It is used in the form of ash as a manure. Potassium occurs in the form of potassium carbonate and percentage of potash is from 2 to 6·5. It is suitable for alkaline soils.

Application of micronutrients. In order to correct the deficiency of micronutrients, especially if it is very necessary, micronutrients should be added only after ascertaining the amount required. Copper, manganese, iron, zinc are supplied generally as their sulphate and boron is applied as borax. Molybdenum is supplied as sodium molybdate. In recent years there has been an increase in use of chelates to supply iron, zinc, manganese and copper.

Soils vary in their ability to supply available nutrients. Some soils may be deficient in nitrogen, some may be deficient in nitrogen and phosphorus, and still some others may be deficient in nitrogen, phosphorus and potassium. To suit the variable requirements of different soils and crops, '*fertilizer mixtures*' are prepared. Fertilizer mixtures or mixed fertilizers contain two or more fertilizer materials. If the ingradients and their amount are known, the formula is referred to as **open** and if they are not disclosed the formula is termed **closed** one.

The kind and amount of fertilizers to be applied to soil are determined considering the following points :

(*a*) Kinds of crop to be grown—particularly its economic value, nutrient removal and absorbing ability.

(*b*) Chemical condition of soil in respect of total nutrients and available nutrients.

(*c*) Physical state of the soil, especially as to moisture content and aeration. For recommending the kind and amount of fertilizers or soil amendments analysis of soil is essential.

2. Application of soil conservation practices

Loss of plant nutrients and water from the soils due to soil erosion can be checked effictively and the fertility of soil can be maintained by application of various biological and engineering methods of soil conservation. A detailed account of these methods is given in soil conservation topic.

3. Water supply and drainage

Water supply is critical factor in crop production in most areas of the world. Soil moisture greatly affects the availability of mineral nutrients in the soil. It has been proved beyond doubt that fertilizer response is much higher with adequate irrigation.

Drainage and moisture control can influence micronutrient solubility in soils. Improving the drainage of acid soils encourages the formation of less toxic oxidized forms of iron and manganese.

4. Prevention and elimination of inorganic chemical contamination of soil

Loss of soil fertility due to application of toxic chemicals as pesticides can be eliminated if (*i*) application of toxic chemical to soil is reduced and (*ii*) the soil and crop are managed as to prevent cycling toxic chemicals.

5. Stabilization of soil pH

The stabilization of soil pH through application of soil amendments and buffering seems to be an effective guard against the problems of non-availability of certain plant nutrients and radical changes in microbial activities arising due to change in soil pH. Several methods are discussed for correction of acidity and alkalinity of soils in the chapter on "Properties of Soil".

QUESTIONS

1. What do you mean by soil fertility ? How does it differ from soil productivity ? Discuss in brief various factors affecting loss of soil fertility.
2. Define soil fertility and describe the methods of checking loss of soil fertility.

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